University of Southern Queensland

Faculty of Engineering and Surveying

Design of a Small-Scale Pyrolysis Machine

A dissertation submitted by

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in fulfilment of the requirements of

ENG4111 and ENG4112 Research Project

towards the degree of

Bachelor of Engineering (Honours) (Mechanical)

Submitted *Month*, 2022

Abstract

This project looks at the design and feasibility of a scalable pyrolysis machine for the production and use of biochar in the agriculture industry as a means of addressing degraded soils and improving food security.

According to the United Nations (2017) The global population is expected to reach 9.8 billion people by 2050. To accommodate the growth in population, agricultural production will need to increase by 60% to meet the growing needs (International Atomic Energy Agency 2022). Climate change and poor soil management practices continue to degrade soils with expectations that 90% of the earth's surface will be degraded by 2050 (Joint Research Centre 2018). This will place the agriculture industry under intense pressure particularly as the effects of climate change is forecast to decrease crop productivity by 10% by then (Joint Research Centre 2018).

The Project is separated into three phases Research, Design and Analysis. The research phase covers a literature review on soil degradation focusing on anthropological impacts, the benefits of char in soil remediation and productivity and identification of sustainable feedstocks for char production. Research was also conducted in various methods for char production to disrupt the natural carbon cycle. In the design and analysis phases computational fluid dynamics will assist in optimising system efficiency.

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Limitations of Use

Certification

I certify that the ideas, designs and experimental work, results, analyses and conclusions set out in this dissertation are entirely my own effort, except where otherwise indicated and acknowledged.

I further certify that the work is original and has not been previously submitted for assessment in any other course or institution, except where specifically stated.

Gregory Allen

Student Number: [redacted]

Acknowledgements

I would like to acknowledge the efforts and support given by my supervisors Dr Les Bowtell, Dr Khalid Saleh and Dr Raid Mahmood who have provided much needed knowledge and guidance throughout the course of this project.

To my partner Amanda, none of this would have been possible without your encouragement and unconditional support over the years. Your belief in me gave me the motivation to persist through the many challenges along the way.

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Glossary of Terms

Activated Carbon: Char that has been thermally or chemically treated to induce small, low volume pores to increase its absorptive capacity

Biochar: is carbonaceous material produced specifically for soil application

Char: Is a general term for any carbonaceous residue resulting from pyrolysis

Charcoal: Is char produced from pyrolysis of organic matter for use in heating or cooking

Hydrophobic: Tending to repel or fail to mix with water.

Leaching: The removal in solution of soluble minerals and salts as water moves through the profile.

Mycorrhizae: Soil fungi that infect plant roots and produce a symbiotic relationship and increases the surface area available for contact with nutrients.

Net Zero: Refers to achieving an overall balance between greenhouse gas emissions produced and greenhouse gas emissions taken out of the atmosphere.

Pyrolysis: The thermal decomposition of materials at elevated temperatures in an inert atmosphere.

Rhyzobia: *Rhyzobium* is a genus of bacteria which can colonise root hairs on legumes and consequently provide nitrogen to the host plant by converting atmospheric nitrogen to a form subsequently useable by host.

Salinity: A measure of the total soluble salts in a soil. A saline soil is one with an accumulation of free salts at the soil surface and/or within the profile affecting plant growth and/or land use. It is generally attributed to changes in land use or natural changes in drainage or climate, which affects the movement of water through the landscape.

Sodicity: Is a measure of exchangeable sodium in relation to other exchangeable cations. It is expressed as the Exchangeable Sodium Percentage (ESP). A sodic soil contains sufficient exchangeable sodium to interfere with the growth of plants, including crops. A soil with an ESP greater than 6 is generally regarded as being a sodic soil in Australia.

Syngas: Is a fuel gas mixture with its composition varying depending on the feedstock used during gasification. Syngas is primarily made up of hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), hydrogen sulphide (H_2S) and carbonyl sulphide (COS).

Chapter 1 Introduction

1.1 Outline

This project looks at the mechanical design and feasibility of a scalable pyrolysis machine for the production and use of char in the agriculture industry as a means of addressing degraded soils and improving food security.

According to the United Nations (2017) The global population is expected to reach 9.8 billion people by 2050. To accommodate the growth in population, agricultural production will need to increase by 60% to meet the growing needs (International Atomic Energy Agency 2022). Climate change and poor soil management practices continue to degrade soils with expectations that 90% of the earth's surface will be degraded by 2050 (Joint Research Centre 2018). This will place the agriculture industry under intense pressure particularly as the effects of climate change (increased weather extremes including droughts, floods, heatwaves, rising sea levels and soil degradation) is forecast to decrease crop productivity by 10% by then (Joint Research Centre 2018).

If temperature averages are permitted to rise beyond 2ºC, the lack of food security will likely lead to malnutrition in large regions, some of which are already vulnerable to humanitarian challenges including Sub-Saharan Africa, South Asia, Central and South America.

To address the impact of climate change and soil degradation, this project aims to address these issues through the design of a small-scale pyrolysis machine for the production of biochar as a soil conditioner in the agriculture industry. Studies have shown that biochar has been an effective means of treating and improving multiple aspects of soil health and crop productivity.

The properties of char offer many benefits to soil such as improving the soil structure, carbon content and water and nutrient retention. Soil structure is a key component in soil health playing an important role in its porosity. The porosity of soil provides an environment for mycorrhizae and rhyzobia to thrive, breaking down nutrients such as carbon, near the plant roots increasing both their access to nutrient uptake, and plant productivity. Porosity also serves as a retention mechanism for nutrients and water leading to greater efficiency in fertiliser application and reduced water application, both of which can lead to leaching of topsoil (erosion) and fertiliser into the waterways.

1.2 Research Objectives

The project's research objectives aim to provide the foundation for understanding the needs, causes and requirements to design and validate a feasible small scale pyrolysis machine.

The project research shall be presented as a literature review and will investigate various aspects relating to the issues and technologies relating to this project. This includes:

- Conducting research to better understand the carbon cycle in the Australian agriculture industry and its impacts on soil carbon levels and soil nutrient cycles.
- Research methods for pyrolysis production and the benefits of biochar and activated carbon use in the agriculture industry.
- Apply engineering knowledge to develop a conceptual design which will be validated against available experimental data from the USQ laboratory.

1.3 Project Outcome

The intent of this project is to provide mechanical design detail for the manufacture of a small-scale pyrolysis machine and supporting research that can be used by independent farmers in the agriculture industry. The following deliverables aim to achieve this intent:

- Detailed mechanical design for a small-scale pyrolysis machine
- Specification for the pyrolysis machine production and output capacity
- Validation of product specification through FEA analysis
- Identification of a suitable feedstock derived from agricultural waste
- Proposed agriculture industries that would benefit from the production and use of char

1.4 Consequences and Implications

1.4.1 Ethical

In line with Engineers Australia's code of ethics and guidelines on professional conduct (2019), the project must use sound knowledge and judgment to engineer a solution that meets the needs for a sustainable future. Failure to do so not only erodes the credibility of engineers and industry bodies, but it also undermines the difficult progress made in transitioning to a sustainable future.

In the absence of strict regulatory requirements, char producers have a responsibility to produce char that is safe and to a specification for its intended use. Failure to do so may lead to undesirable changes to the soil or negative environmental conditions and risk the health of living organisms.
Routine maintenance of equipment is vital to ensure correct operation and proper working condition of the system. This will be difficult to enforce in a farm environment particularly if there is a "if it isn't broke, why fix it" ethos.

1.4.2 Safety

Toxic char residues and volatiles can be harmful to humans and livestock. The producer of char have a responsibility to those operating the system to have an appreciation of the basic process and the potential for toxic substances to be emitted from the equipment or from the char and how this can be avoided.

Pyrolysis occurs between 350ºC and 1000ºC which can pose a fire hazard. Many large farms are relatively isolated so operators must consider the production, storage and transportation of char and have a fire safety plan in place.

The production of char as opposed to traditional slash and burn of agriculture waste reduces the number of pollutants entering the atmosphere that would otherwise pose a hazard to the respiratory health of neighbouring communities.

1.4.3 Socio-economic

Soil degradation and the impacts of climate change on food security requires the agriculture industry to sustainably innovate and adapt to meet the needs of a growing population. Biochar has shown great promise in increasing soil and crop productivity along with potentially offering additional revenue through the on-selling of carbon credits to offset emissions for large corporations.

One of the challenges faced by char’s future in agriculture is the immediate increase in labour, and subsequently cost, to transition away from traditional agriculture practices, toward char production and processing. However, without sufficient uptake and support for char production, the innovation required to reduce labour or improve efficiency may prove too much for the remaining market.

1.4.4 Environmental

The known environmental benefits of char are increasing as further research arises. The physical properties of activated carbon and biochar make it highly absorbent and can be added to cattle feed to reduce methane emissions or added to soil to reduce nutrient leaching by retaining fertiliser nutrients which, as documented by the Great Barrier Reef Marine Park Authority (2022), has been a contributor to the decline of the great barrier reef. Alternatively, biochar can be incorporated into soil to improve soil health and biodiversity while simultaneously offering a means to offset emissions to reach Net Zero through carbon sequestration.

Chapter 2 Literature Review

2.1 Introduction

Since the rise of agriculture practices nearly 10,000 years ago, mankind transitioned from hunter gatherers into the mass food production we see today. This, in combination with advanced medicines and the industrial revolution, has given rise to an explosion in the population from an estimated 5 million to nearly 7.9 billion people (World Population Clock 2021).

The growth in human population has put an incredible strain on food security and earth’s resources leading to soil degradation through unsustainable agriculture practices, climate change and soil pollution (Kavitha et al. 2018, pp. 146-154; Blair et al. 2006, pp. 48-56).

Degradation of soil can have a negatively impact on microbial interactions in the soil region surrounding the plant root (rhizosphere) and the symbiotic fungus (mycorrhizal) that plays an important role in plant nutrition and soil properties (Eskandari et al. 2018, pp. 199-201).

2.2 Australian Soils

Australian soil is among the oldest and most nutrient poor in the world. This is largely due to the country’s geological stability which prevents the natural creation of new soil (DAWE 2021, p. 12).

Formation of new Australian soils is a slow process with averages from 10mm to 75mm every 1000 years, well below the global average of 114mm. Much of Australia's soils are in such poor condition that the rate of soil erosion exceeds the formation rate (Metcalfe & Bui 2016).

Degradation of Australian soils results in the loss of productivity and biodiversity as a result of acidification, erosion, salinisation, waterlogging, depletion of soil structure, nutrients and organic matter, desertification and contamination (Campbell 2008, p. 11).

The continued productivity of Australian soils is highly reliant on the supply of water. Nearly 90% of the country's landscape does not receive sufficient water for 9-12 months each year to sustain plant growth in the agriculture industry (Australian Bureau of Statistics 2012).

In May 2021, the Australian government announced in the federal budget an additional $196.9 million of new funding to implement the National Soil Strategy. This funding aims to show how Australia will value, manage, and improve its soil over the coming 20 years. The goal of the National Soil

Strategy centres around prioritising soil health, promoting innovation and stewardship and strengthening soil knowledge and capability (DAWE 2021, p. 4-5).

2.3 Soil Properties

2.3.1 Physical Soil Properties

Soil Texture is indicative of the size and quantity of the soil particles which vary with the proportion of sand, silt, clay and organic matter. A soil's texture can be categorised based on the dominant particles such as sand, loam, clay and silt as shown in Figure 1 (Stockdale 2022a).

Soil texture is a foundation property of soil which can influence its ability to permit the movement of air, water and nutrients (Stockdale 2022a).

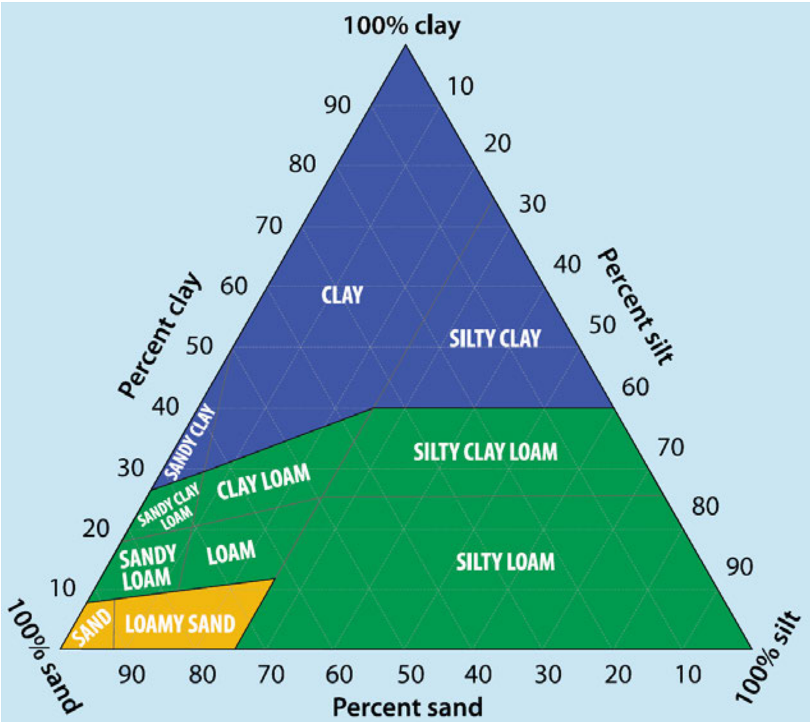


Figure 1: Soil texture classes (Stockdale 2022a)

Data compiled by Soil and Landscape Grid of Australia (2022) indicate that Australian soils at a depth of 15-100cm have a tendency to reduce in sand content with depth with the majority of soil averaging 60% sand content. The dispersion of clay however increases with depth, particularly the northern and eastern parts of the country where clay accounts for at least 45% of the soil mixture. The western and southern states contain clay in the vicinity of 20%. Silt remains relatively consistent throughout the upper soil profile averaging 5-10%. Based on the data presented in Figure 2, Dispersion of clay in

Australian soil (Soil and Landscape Grid of Australia 2022)Figure 3 and Figure 4, large parts of Western and South Australia could be classified as sandy loam, while the east and some parts of the north fall into sandy clay.

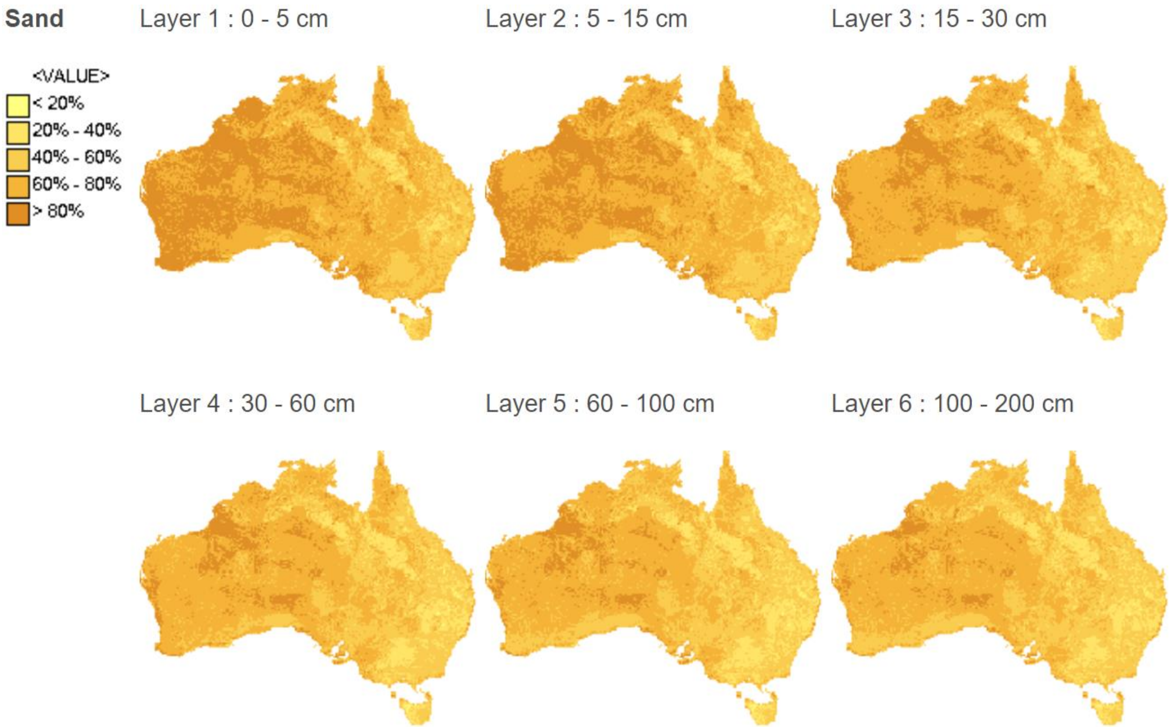


Figure 2: Dispersion of sand in Australian soil (Soil and Landscape Grid of Australia 2022)

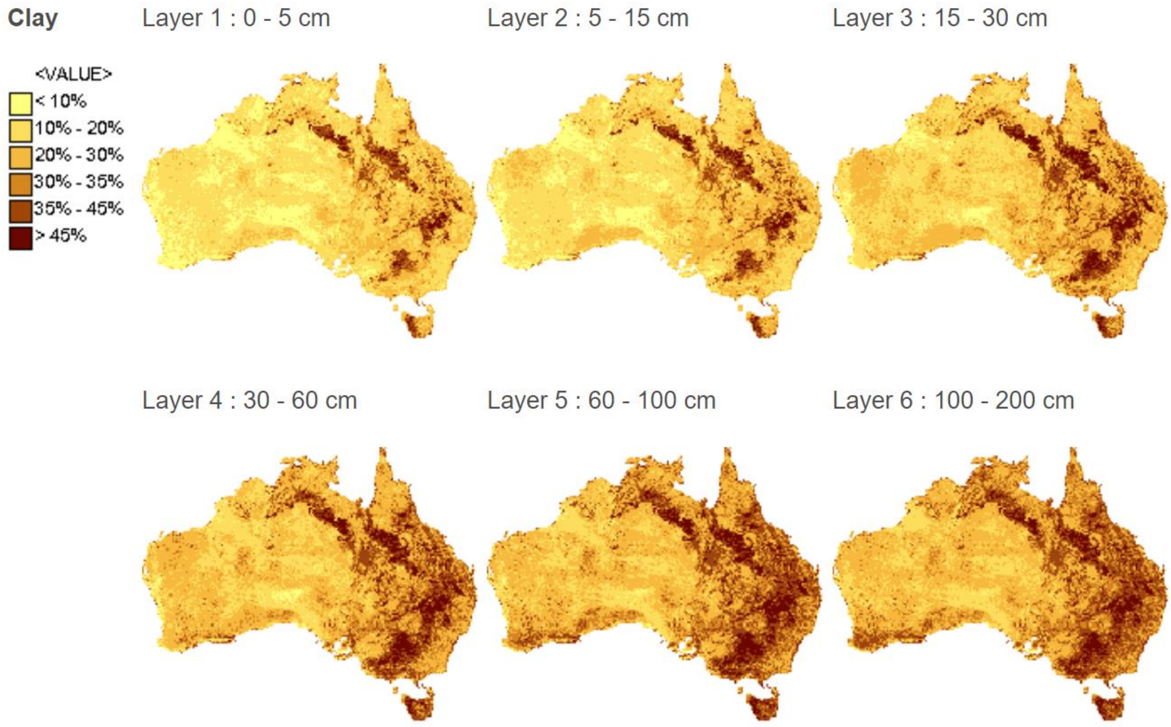


Figure 3: Dispersion of clay in Australian soil (Soil and Landscape Grid of Australia 2022)

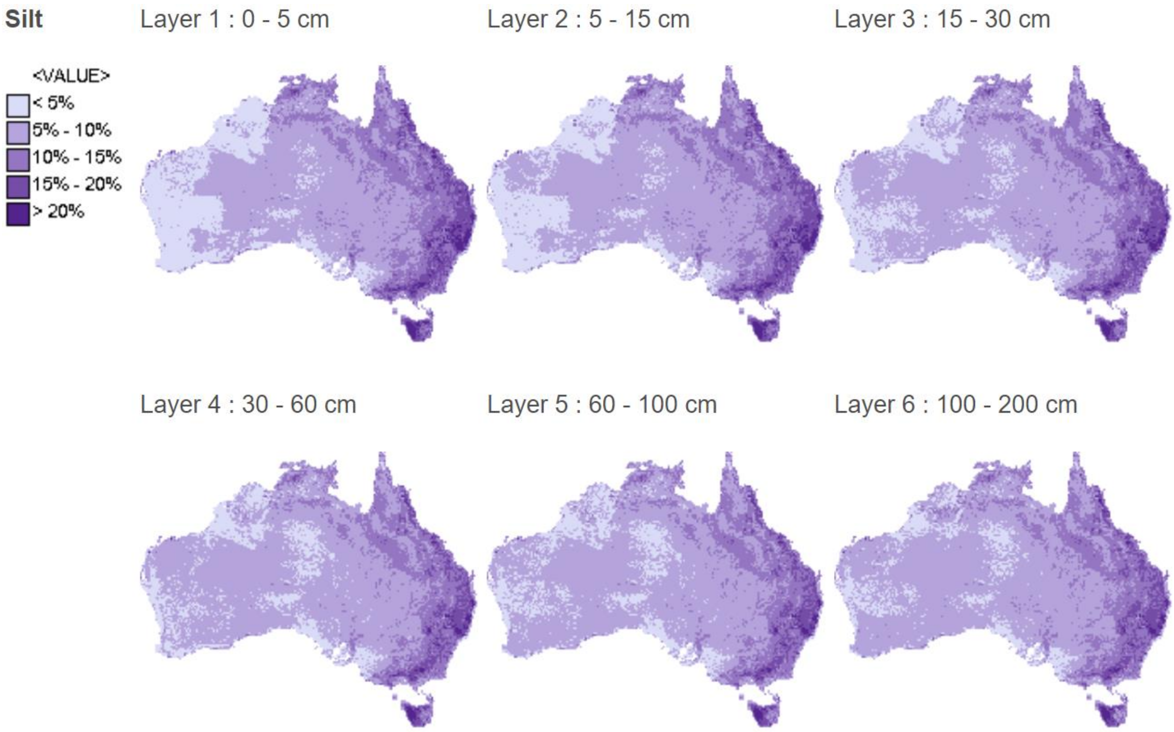


Figure 4: Dispersion of silt in Australian soil (Soil and Landscape Grid of Australia 2022)

Gravel Content can negatively influence a soils water holding capacity while providing benefits for reducing risk of erosion and compaction and promoting root growth (Stockdale 2022a).

Bulk Density indicates a soil's overall porosity and typically does not account for gravel content. higher bulk density can lead to poor root growth (Stockdale 2022a).

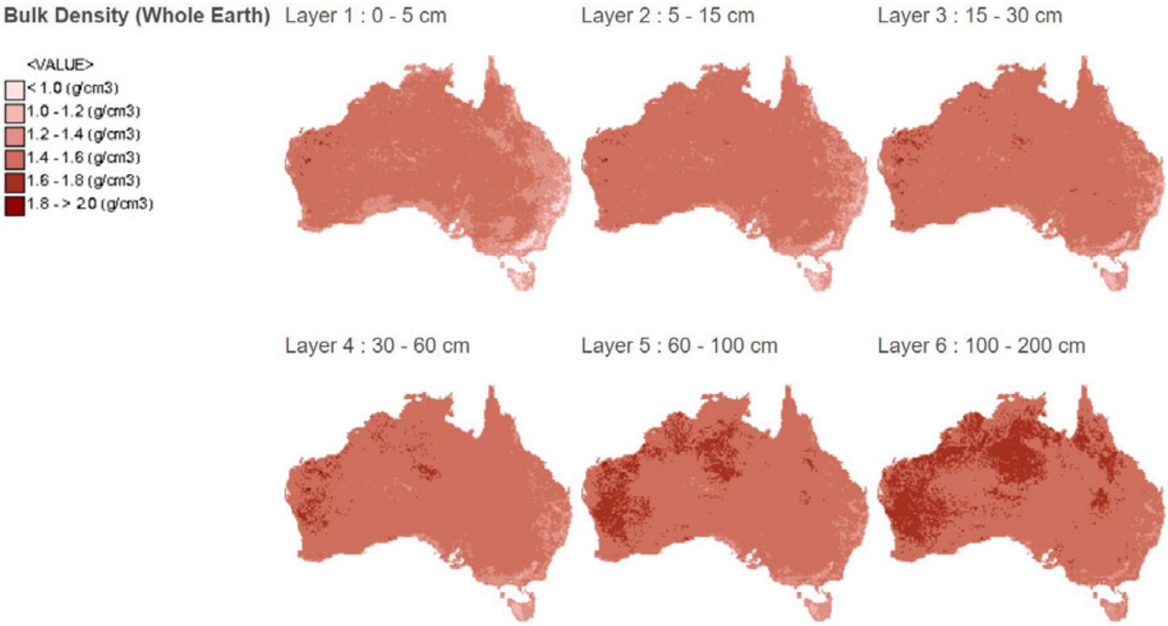


Figure 5: Bulk density of Australian soil (Soil and Landscape Grid of Australia 2022)

Water Holding Capacity has a strong correlation with soil texture which describes the particle pore size present in a soil. Improving the structure in predominantly clay soils promotes drainage while improvement to sandy soil structure increases the water holding capacity (Stockdale 2022a).

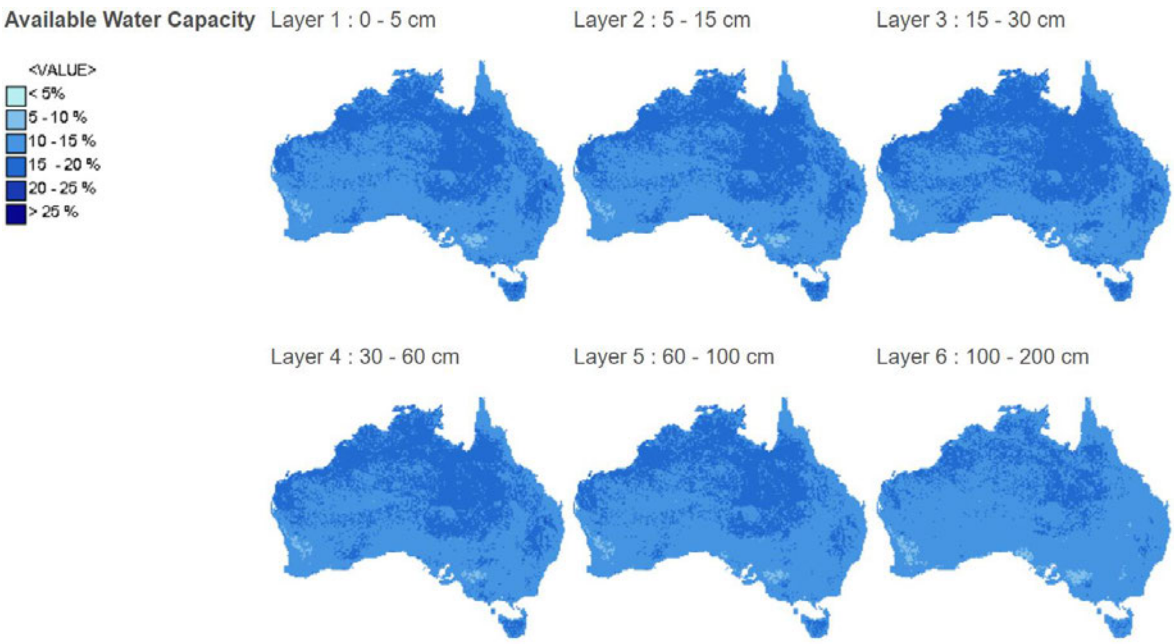


Figure 6: Water holding capacity of Australian soil (Soil and Landscape Grid of Australia 2022)

2.3.2 Chemical Soil Properties

Soil chemical indicators are a measure of the dynamic nature of soil which vary over time and can be impacted through soil management practices (Stockdale 2022b).

Soil pH indicates the scaled concentration of hydrogen ions in the soil ranging from 1 to 14, where 1 indicates a highly acidic and 14 alkaline soil. Acidic soils can restrict microbial activity, negatively impact nutrient availability and limit root growth (Stockdale 2022b). Data presented in Figure 8 by Soil and Landscape Grid of Australia (2022) indicate a decrease in acidity at deeper soil profiles with slightly acidic soils in large parts of the upper 30cm profile of the western and northern parts of the continent. When this data is applied to Figure 7 it is evident that there is considerable need for soil conditioning to maintain the current and future agriculture industry.

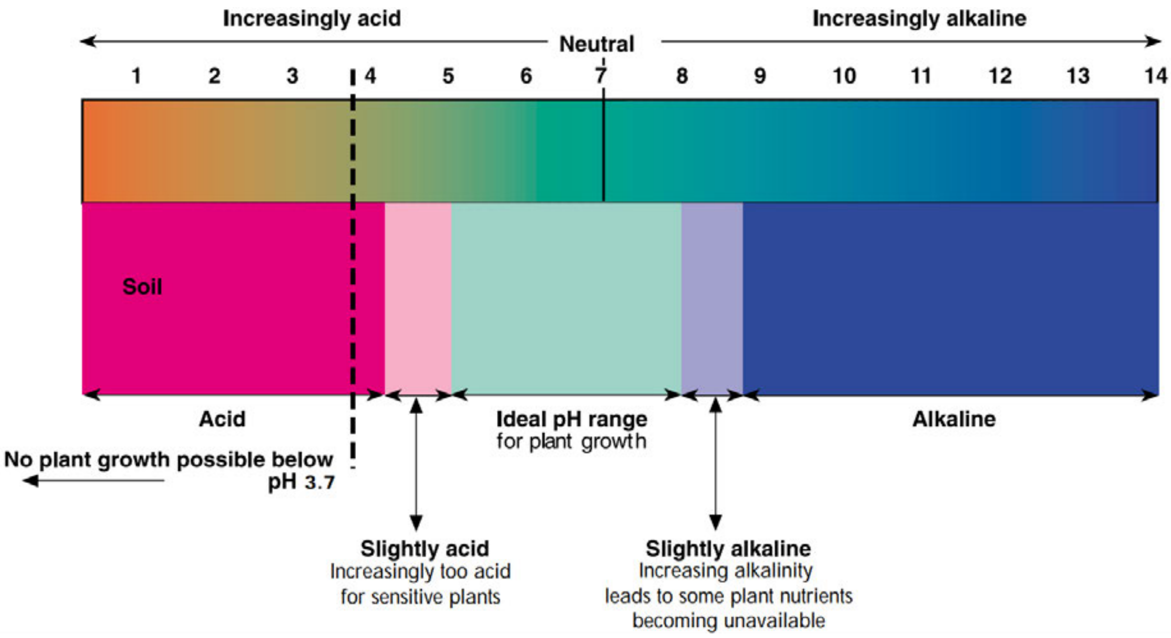


Figure 7: Plant growth and pH scale (Lake 2000)

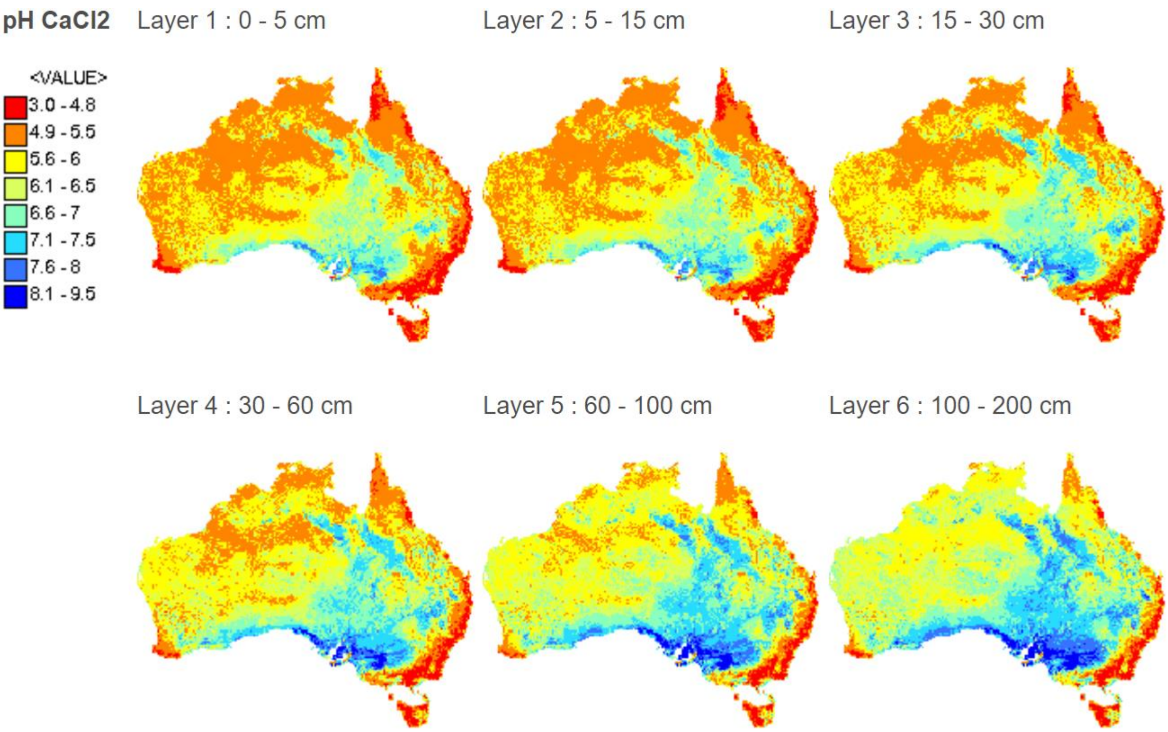


Figure 8: Acidity and alkalinity in Australian soil (Soil and Landscape Grid of Australia 2022)

Electrical Conductivity provides an indicator of the concentration of soluble salts and is commonly used as a means of identifying soil salinity. High levels of salinity can limit plant growth and lead to plant stress (leaf necrosis) (Stockdale 2022b).

Water Repellency impacts over 5 million hectares of the grain growing regions of Southern and Western Australia. Water repellency occurs when waxy plant residue coat soil particles preventing water from penetrating the soil surface. This is a common attribute in sandy soils or soils with a clay content below 10% (Stockdale 2022b). Water repellency results in uneven soil irrigation, poor seed germination and an increase in wind and water erosion with an estimated annual loss of productivity costing in excess of $100M (CSIRO 2021).

Nutrients - Soil nutrient availability such as nitrogen, phosphorus and potassium are complex and vary with agriculture practices through the use of fertilisers and crop rotation (Stockdale 2022b).

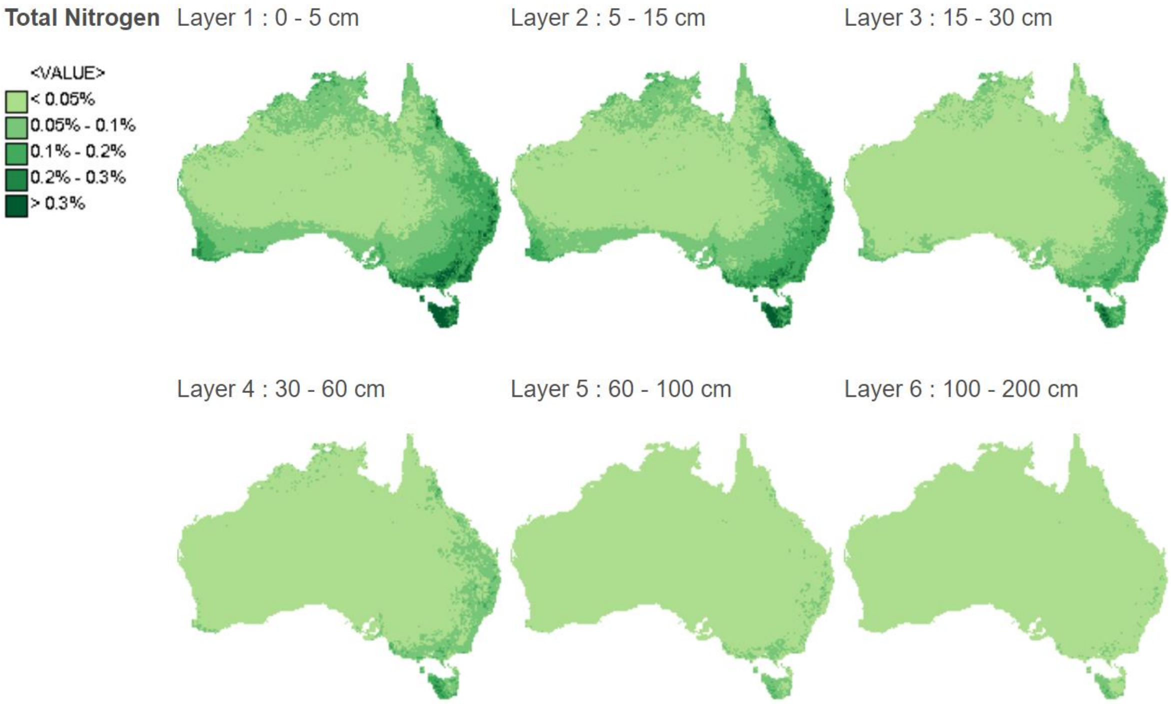


Figure 9: Total nitrogen in Australian soil (Soil and Landscape Grid of Australia 2022)

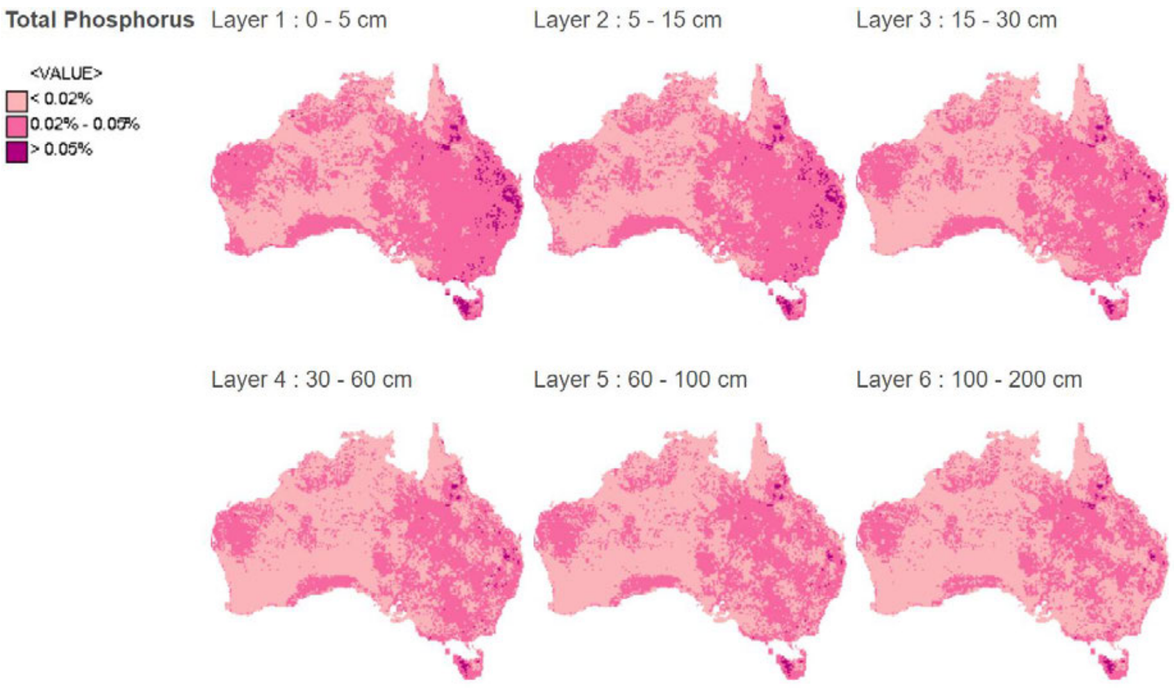


Figure 10: Total phosphorus in Australian soil (Soil and Landscape Grid of Australia 2022)

Cation Exchange Capacity is an inherent soil property relating to soil texture and minerals present in the parent soil material. CEC increases with organic matter and clay and typically ranges from 1 to 15 milliequivalents per 100 grams of soil. Crop productivity is unlikely to occur in soils with a CEC below 10 with very low levels indicating little effect from added potassium and magnesium fertiliser. If the soil samples electrical conductivity is high, this may affect the accuracy of the CEC (Stockdale 2022b).

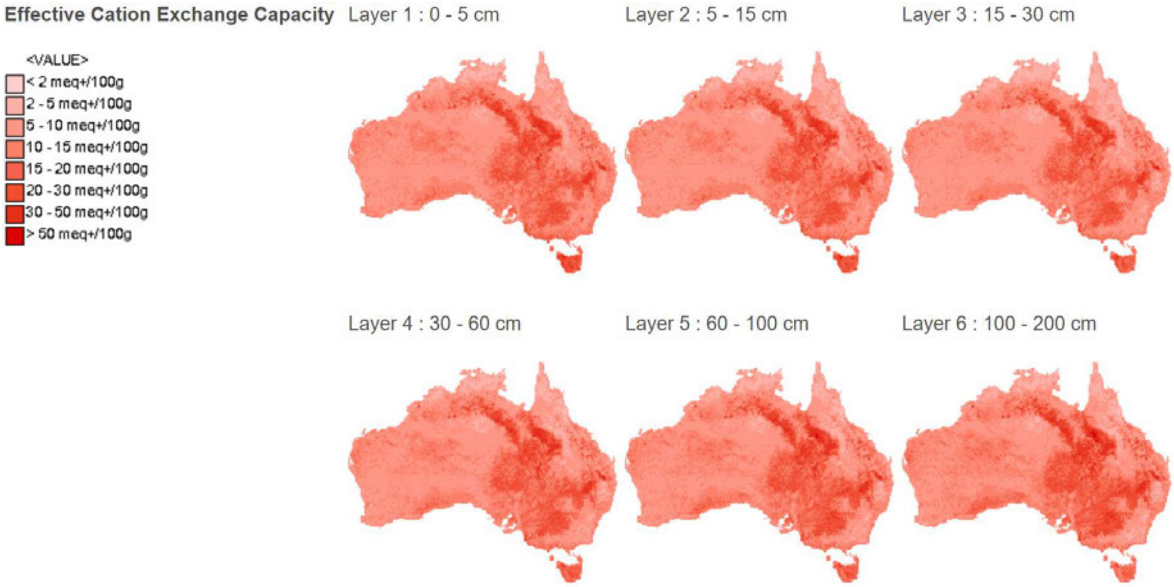


Figure 11: Effective CEC of Australian soil (Soil and Landscape Grid of Australia 2022)

2.3.3 Biological Properties

Total Organic Carbon is an indicator of the organic material present in the soil and is expressed as a percentage. Low levels indicate there may be issues with the soil structure, low cation exchange capacity and nutrient turnover. Organic carbon levels in soil can be improved through soil management practices (Stockdale 2022c).

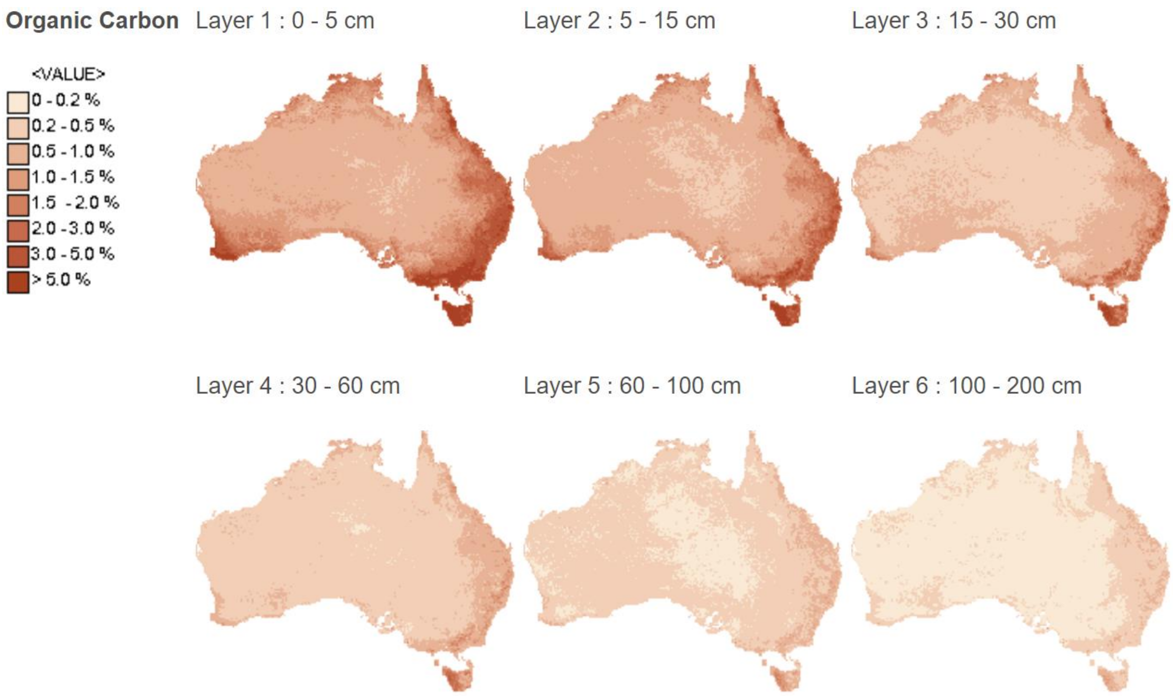


Figure 12: Organic carbon content of Australian soil (Soil and Landscape Grid of Australia 2022)

Microbial Biomass comprises of bacteria and fungi present in the soil which play a vital role in the interaction between the soil and plant root system by decomposing organic matter to release carbon dioxide and nutrients like nitrogen for plant uptake. Microbial biomass is heavily influenced by carbon and water content of the soil. Retaining crop residues has been shown to be more effective in increasing microbial biomass than burning them (Stockdale 2022c).

2.4 Impact of Agriculture on Soil Quality

It is widely accepted that since Europeans settled in Australia, excessive deforestation of deep-rooted perennial native vegetation for cropping and grazing has enabled greater quantities of water to enter the groundwater system leading to the mobilisation and concentrations of sodium within the upper soil profile (Fitzpatrick et al. 1994, p. 1071).

Agricultural practices such as the use of various tillage methods, fertiliser, crop rotation and fallowing can degrade the soils by decreasing carbon and nitrogen content, lead to increased bulk density (compaction) and reduced crop yields (Blair et al. 2006, pp. 48-56; Bell et al. 2011, pp. 19-29 & Alam et al. 2020, pp. 107-130).

There are numerous varieties in soil types used in agriculture, sodic soils of which more than 50% worldwide can be found in Australia, degrades soil as it has high salinity, restricts plant root growth, has low porosity, low oxygen concentration and hydraulic conductivity (Eskandari et al. 2018, pp. 199-201).

Soil sodicity occurs where there is a high proportion of sodium ions to other cations within the soil. Sodium particles remain bound to clay particles displacing other cations. High levels of sodium degrade soil by weakening the cohesion of soil particles. The effects of sodicity increases dispersion in the soil surface which reduces soil water infiltration preventing water flow through the soil which enables an accumulation of saline subsoils (Queensland Government 2021).

Soil sodification negatively impacts soil structure leading to hillslope and watercourse erosion and waterlogging. The increased sodium and colloidal loading on water catchment areas can reduce water storage capacities and create water quality issues (Fitzpatrick et al. 1994, p. 1069-70).

Currently, Agricultural sodic soils are commonly managed through the application of lime (in soils pH <5) or gypsum (1-5 t/ha), organic matter or planting sodic tolerant crops. The application of gypsum is dependent on the severity of sodicity ranging from seasonally to once every decade and is critical just prior to sowing to avoid leaching from irrigation or rain (Fitzpatrick et al. 1994, p. 1087;

Moore 2001, p. 145; Department of Primary Industries and Regional Development 2021; Australian Academy of Science 2015 & McMullen 2000, p. D5.3).

The Australian Soil Classification (ASC) broadly categorises soil types into 14 groups. Of these 14, eight are considered sodic – Sodosol, Kurosol, Hydrosol, Chromosol, Dermosol, Kandosol, Calcarosol and Vertosol.

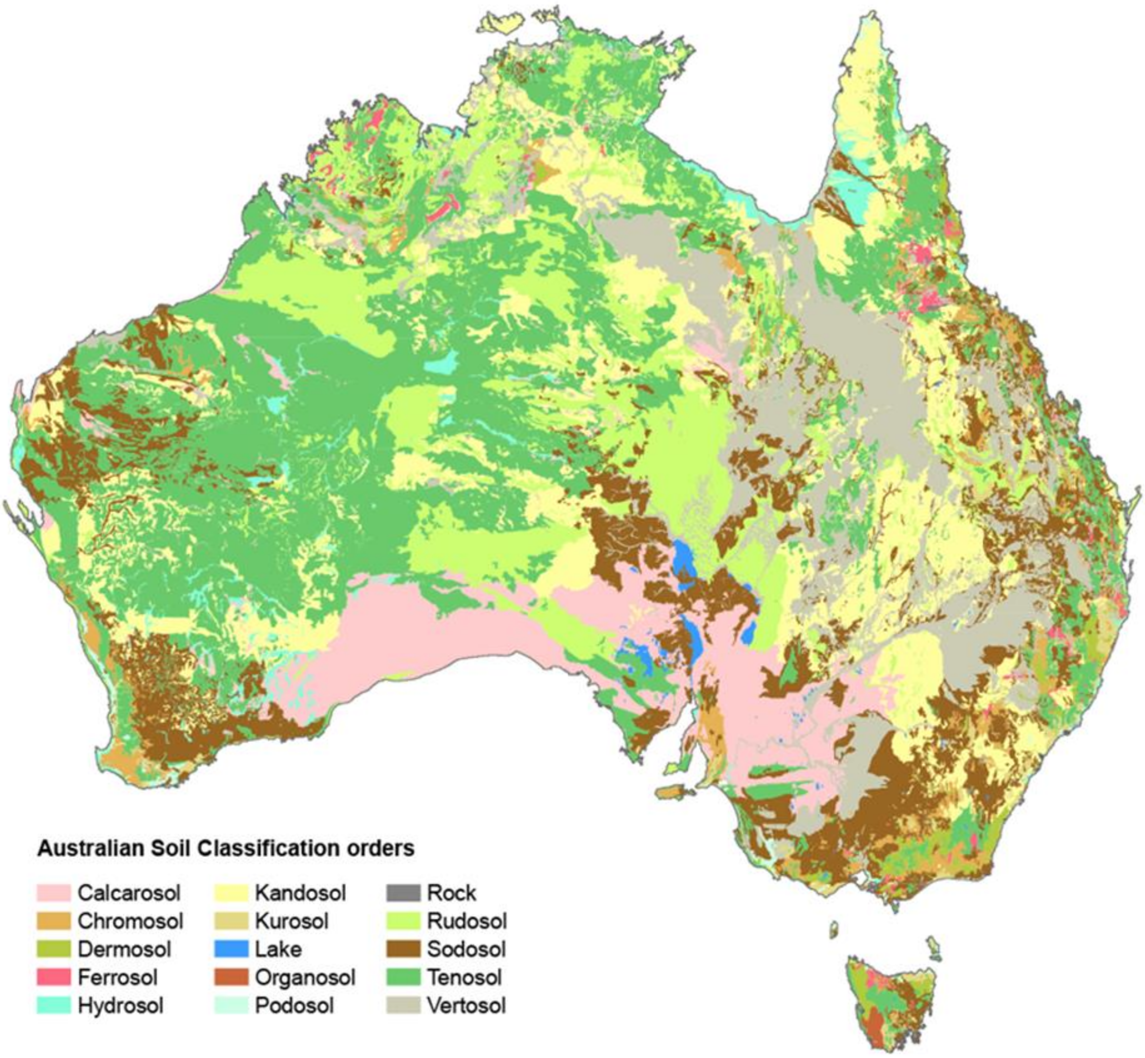


Figure 13: Australian Soil Map (Australian Soil Classification Orders, 2018)

2.5 Impact of Climate Change on Soil Quality

Climate change has seen an average temperature rise of 1°C since 1950 and a reduction in average winter season rainfall across many parts of southwest and southeast Australia (ABARES 2021a). Reduced rainfall has led to drought and an estimated 35% reduction in productivity for Australian cropping farms (ABARES 2021b). While a reduction in rainfall will lead to drier topsoil which is vulnerable to erosion, the increased frequency in extreme weather events will exacerbate the rate of erosion. The Office of Environment and Heritage (2018), suggests that a correlation exists between soil moisture content, environmental temperatures and soil organic carbon - an indicator of soil health. A decline in rainfall and increase in average temperature is expected to affect the overall SOC in NSW with projections indicating a decline by 5.1t/ha with some highland regions such as Mount Kosciuszko National Park, which is a rare alpine ecosystem in Australia, expected to decrease by as much as 20t/ha by 2079. The impact of climate change and soils degraded through sodicity, the Australian agriculture industry faces increasing challenges in the coming century.

2.6 Impact of Pollution on Soil Quality

Soil pollution in Australia primarily occurs as a result of industrial, agriculture and waste disposal activities. Industrial activities like mining, which can mobilise and disperse both nutrients, toxic chemicals and heavy metals into the water table leading to widespread areas impacted (Prematuri, Turjaman, Sato & Tawaraya 2020). Agriculture pollution arise from the use of pesticides and fertilisers which, if poorly managed, often enter nearby rivers and oceans which can destroy natural ecosystems. According to the Basel summary report (Latimer 2022, p. 1-3), over 2.5 million tonnes of contaminated soil was generated in 2020-21 (up from 1.5 million in 2010), with approximately 1.6 million tonnes going to landfill. Waste disposal from industrial and municipal sources is disposed of in landfill without undergoing treatment where it can cause further contamination at the waste site. Soil pollution negatively impacts the physical, chemical and biological properties of the soil profile leading to adverse health impacts, reduced productivity (Ranieri, Bombardelli, Gikas & Chiaia 2016, p.1).

2.7 Agriculture Industries

While variation in land use from one year to the next can lead to discrepancies in data available, the data and figures presented here are purely indicative. According to ABARES (2022) and the Australian Bureau of Statistics (2021b), the agriculture industry in Australia accounts for 49% (377 million Ha) of land use roughly broken down into 325 million hectares for grazing, 31 million hectares for cropping and 0.5 million hectares for horticulture. In the 20 years since 2002, the agriculture, fisheries and forestry sectors have increased in production value to $75 billion (+7%) distributed across each sector as shown in Figure 15.

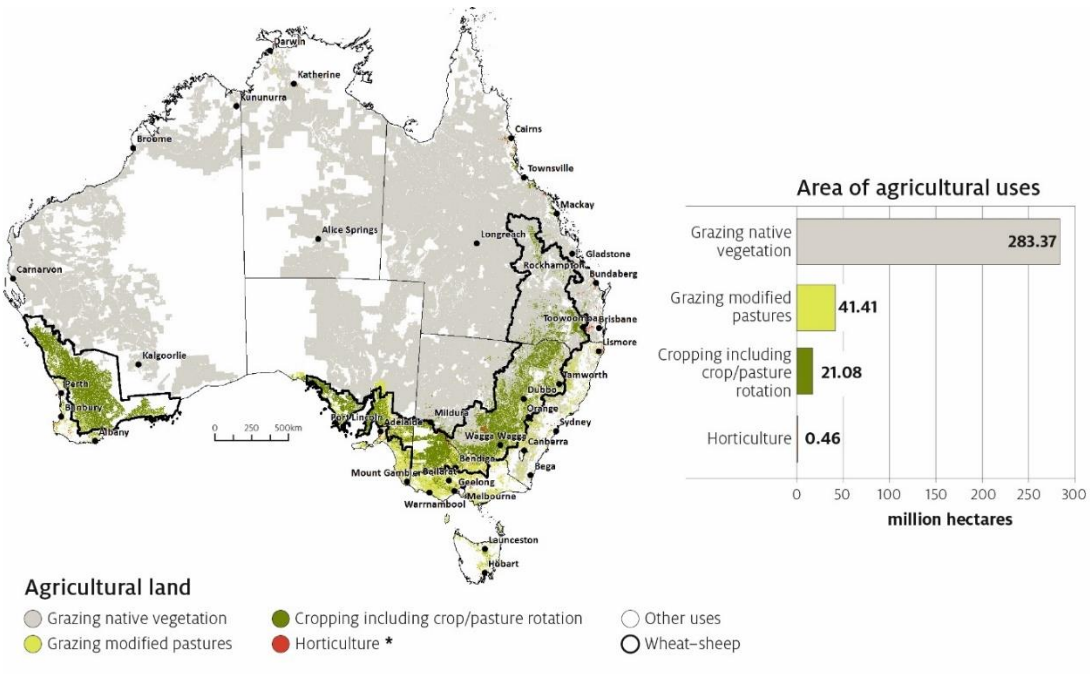


Figure 14: Agricultural production zones (ABARES 2022, p. 1-14)

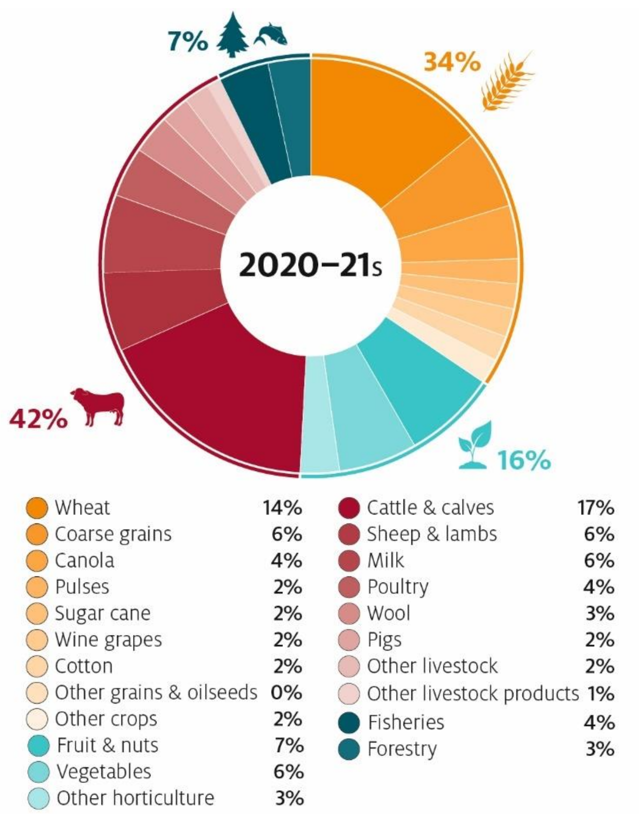


Figure 15: Agriculture, fisheries and forestry value of production, by commodity (ABARES 2022, p. 1-14).

2.8 Agriculture Practices and its Impact on Soil Degradation

In NSW soil acidification has increased through land use and management practices which reduces soil health and plant growth. Soil acidification typically occurs in the surface layers however, if remedial action is not taken it can reach the lower layers becoming increasingly difficult to manage. Practices such as the removal of agricultural produce, addition of nitrogen-based fertilisers and nitrates can lead to further soil acidity and degradation (Chapman et al. 2011, p. 13).

According to Fenton & Helyar (2002) as soils increase in acidity, the availability of aluminium increases to toxic levels restricting root development with molybdenum: necessary in the conversion of nitrates to useful ammonia and other plant nutrients like phosphorus, magnesium and calcium decreasing. Crops such as wheat, canola and barley are sensitive to high levels of aluminium. Liming is one method used in agricultural practices to manage soil acidity Fenton & Helyar (2007).

Soil carbon levels usually have a higher concentration in the surface layer where organic matter is produced. Carbon plays an important role in a soils physical, chemical and biological processes necessary for soil productivity. Land management practices such as the removal of organic material, soil disturbances (tillage, cultivation etc), fire and fallowing all contribute negatively to soil carbon.

The physical soil structure is pivotal in the exchange of water and gas between the soil and atmosphere and plays an important role in soil health and productivity. Considerable time and money may be required to rectify soils with a degraded soil structure particularly those that contain high levels of sodium (sodic). Soil structure is sensitive to land management practices on fragile soils such as compaction from machinery and livestock on moist soil, tillage and the burning crop stubble.

Much of Australia's soils are naturally impacted by soil salinity as soluble salts are deposited in the upper soil layers from the groundwater. Areas affected by salinity have a severe impact on soil and vegetation. Soil salinity can be caused and exacerbated through poor land management practices such as land clearing, irrigation and disruption the natural environment.

2.9 Biochar

Biochar is the carbon-rich by-product of organic biomass that has undergone thermal decomposition in little to no oxygen. Studies have shown the benefits of biochar as a soil conditioner that increases soil porosity, microbial growth, carbon sequestration, water retention and crop yields (Alam et al. 2020, pp. 107-130; Palansooriya et al. 2019, pp. 52-64; Cely et al. 2015, pp. 173-182; Blanco-Canqui 2017, pp.146-154 & Kavitha et al. 2018, pp. 146-154).

The production of biochar interrupts the natural carbon cycle as shown in Figure 16 where organic material, which would normally decompose releasing carbon back into the atmosphere, is otherwise carbonised through pyrolysis. Through this process, the carbonised material, in the form of biochar, can be repurposed as sequestered carbon as a means of tackling climate change. One common characteristic of biochars is its rate of decomposition is far lower than that of the original feedstock, often taking anywhere between decades and a millennia to break down.

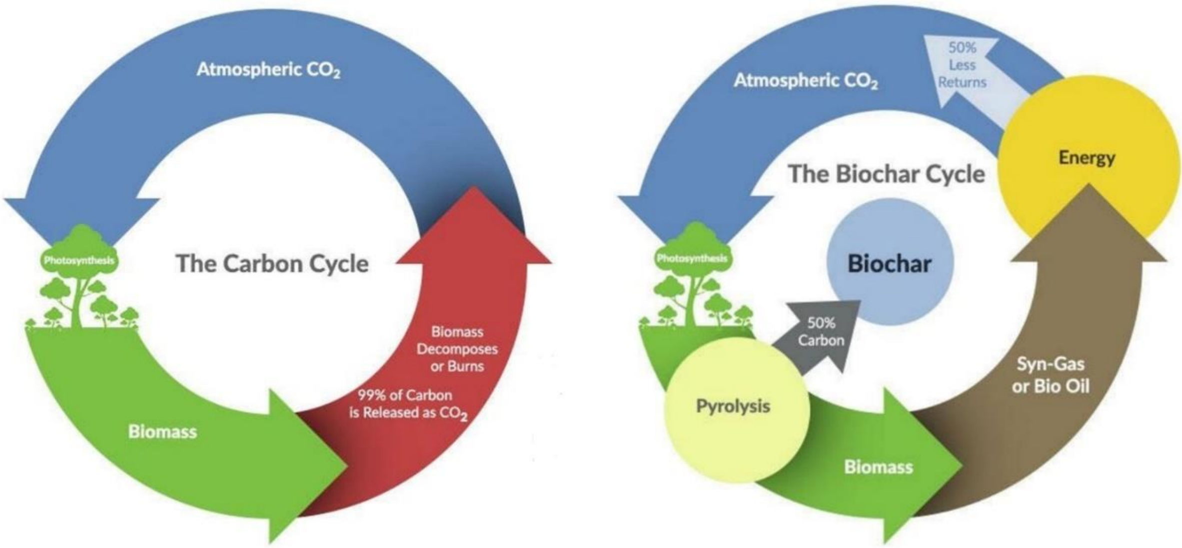


Figure 16: Natural Carbon vs Biochar Cycle (Coyne 2021, p.10)

Selection of feedstock (biomass) and pyrolysis method is critical in determining the biochar properties which need to be carefully considered for the intended soil type or there may be negative impacts with some studies showing reductions in earthworms and mycorrhizal which play important roles in a healthy soil biota (Kavitha et al. 2018, pp. 146-154).

According to Fuchs, Garcia-Perez, Small & Flora (2014) the production of char undergoes five distinct stages:

1. Below 200℃ - evaporation of moisture and the production of white smoke
2. 200 and 300℃ - Torrefaction, the decomposition of biomass and release of acetic acidic smoke with an unpleasant odour
3. 300 and 650℃ - Pyrolysis, further decomposition with the release of vaporised oils and tars that will ignite in the presence of oxygen
4. Above 650℃ - the flame disappears, and char begins to glow as it oxidises
5. Ash forms when the carbonaceous material has been fully oxidised

2.9.1 Biochar Properties

Biochar properties are dependent on many factors such as the original feedstock and the production method. This enables the biochar properties to be modified to meet the end user requirements. Biochar properties can be broadly categorised into the following properties:

- Content - carbon, hydrogen, nitrogen, sulphur and oxygen content
- Composition
- Physical characteristics - surface area, pore size and surface chemistry

Fuchs, Garcia-Perez, Small & Flora (2014), suggest that the general properties which are beneficial to soil application are:

1. High carbon content (>70%)
2. Low ash content
3. High surface area (approx. $300m^2/g$)
4. Low volatile content
5. Moderate pH (7-9.5)
6. Capacity to neutralise acidic soil

The temperature plays a key role in the properties of biochar with a decrease in remaining volatiles and an increase in carbon and ash as temperature increases.

Previous research indicates biochars produced at temperatures above 550℃ generally have surface areas above $400m^2/g$ and are resistant to decomposition. Conversely, pyrolysis below 550℃ retains higher carbon and nutrients providing a greater contribution to soil fertility (Joseph, Camps-Arbestain, Lin, Munroe, Chia, Hook, van Zwieten, Kimber, Cowie, Singh, Lehmann Foidl, Smernik & Amonette 2010, p. 501-502).

Studies have shown that biochar prepared using rice husks and corn stalks under slow pyrolysis, in combination with plant growth-promoting rhizobacteria (PGPR) significantly improved the soil biota and physiochemical properties while reducing the exchangeable sodium percentage (ESP) and sodium content in sodic-saline soils (Nehela et al. 2021).

2.9.2 Biochar Uses

According to Schmidt & Wilson (2014) the potential application and use for char are widely varied and care must be taken to ensure char of a sufficient quality standard is used to avoid adverse results, applications have been categorised as follows:

Soil Conditioning of degraded soils have seen great improvements with the addition of biochar which has seen improved soil structure, fertility, nutrient retention and water holding capacity which is suitable for Australian soil given its current state of degradation and water shortages.

In Agriculture, char can be added as a soil conditioner for the benefit of crops productivity or used in the livestock sector. While the benefit of soil conditioning has been described previously, the use of char in the livestock industry as a feed supplement, has been shown to reduce methane production and nutrient uptake thereby improving the overall health of livestock. Char can also be applied directly to animal waste as a litter, reducing undesirable odours.

Construction Industry char has a low thermal conductivity and high water holding capacity making it an ideal material for building insulation and regulating humidity. Applied as a substitute for sand in cement and render, char could provide additional insulation in building external structures with its absorption properties acting as a carbon sink.

Decontamination of Soil and Water leveraging off chars' absorption properties enable it to sponge contaminates such as heavy metals from mine sites and landfill, pesticides and fertilizers from agriculture soils and water runoff and the treatment of wastewater emissions, contaminants and odour.

Biogas Production can be optimised with Studies showing that with the addition of char to a fermenter, increases to methane and hydrogen occurred while a reduction in carbon dioxide and ammonia emissions were observed.

Medicinal grade char as described in agriculture applications, can also be applied to medical applications such as a detoxifier, cholesterol management, improves kidney function and teeth whitening.

2.9.3 Char Production Methods

The carbonisation of biomass can be divided into three processes, pyrolysis, gasification and combustion and is frequently observed in the burning of a match as depicted in Figure 17. Pyrolysis is the first stage of combustion and occurs when biomass is heated and begins to release volatile gases and tars as the material breaks down. As gases and tars are released, they ignite are combusted leaving behind the charred remnants of the biomass which can continue to burn in the presence of oxygen.

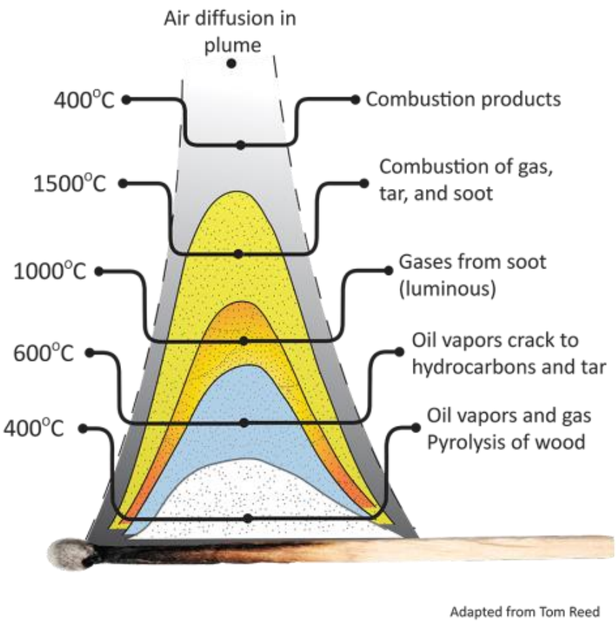


Figure 17: Pyrolysis, gasification and combustion in a flaming match (All Power Labs 2022a)

Pyrolyser Systems typically operate between 350℃ and 650℃ in the absence of oxygen. Charcoals produced at temperatures below 450℃ are likely to contain volatile materials such as oils and tars that can be used as a fuel source. Pyrolysis can be broken down further into slow and fast pyrolysis to indicate the production heating rate. The heating rate can be useful in influencing specific properties of the char, depending on its intended use.

Slow Pyrolysis is a process where the biomass undergoes transformation with lower heating rate, peak temperature and long residence times resulting in larger quantities of syngas. This method, typically using earth kilns or pits, can produce char containing 25% to 35% of the original feedstock weight and 50% of its carbon (Fuchs, Garcia-Perez, Small & Flora 2014).

Fast Pyrolysis requires finer feedstock which is then subjected to heat with the organic decomposition occurring in a matter of minutes or seconds. This method produces more oil and liquids and can lead to volatiles remaining in the char after the process has completed. Fast pyrolysis can convert up to 75% of the original biomass into bio-oil (Fuchs, Garcia-Perez, Small & Flora 2014)

Kilns are relatively simple in construction and operation. Kilns typically work on a single batch basis with the exception of the continuous multiple hearth kiln. Char production is achieved when the biomass is placed in the pit, mound or kiln and combustion is monitored in three stages drying; pyrolysis and completion which is identified through the colour of smoke emitted, white, yellow and blue respectively. Disadvantages to kiln type char production is low char yields, inconsistent uniformity and air and soil contamination.

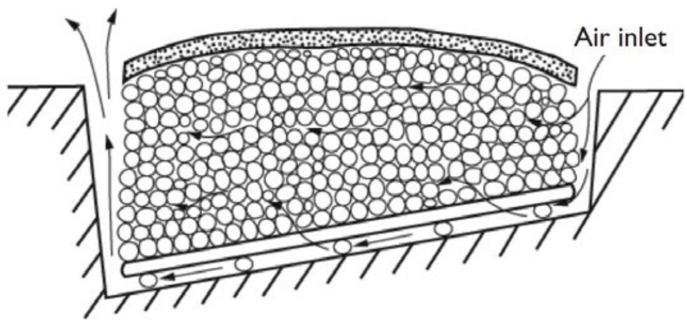


Figure 18: Pit kiln (Lehmann & Joseph 2009)

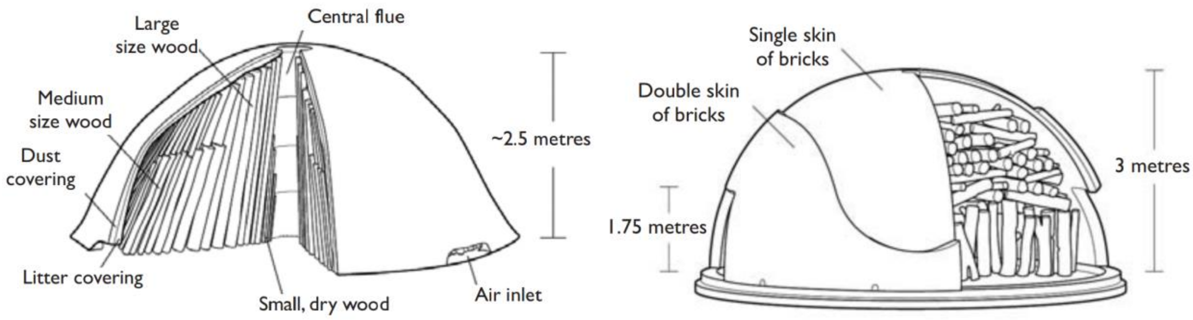


Figure 19: Mound and brick kilns (Lehmann & Joseph 2009)

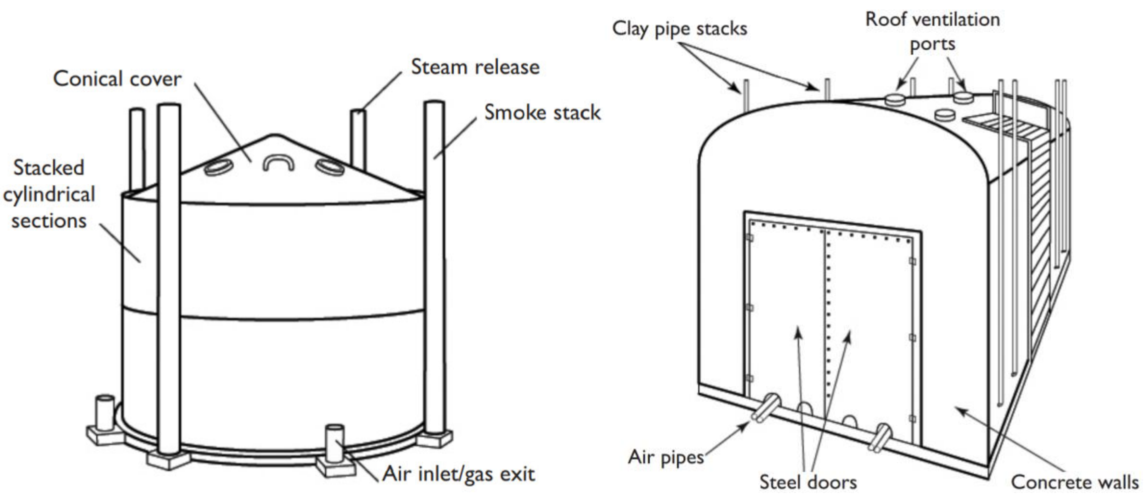


Figure 20: Metal and Missouri-type kilns (Lehmann & Joseph 2009)

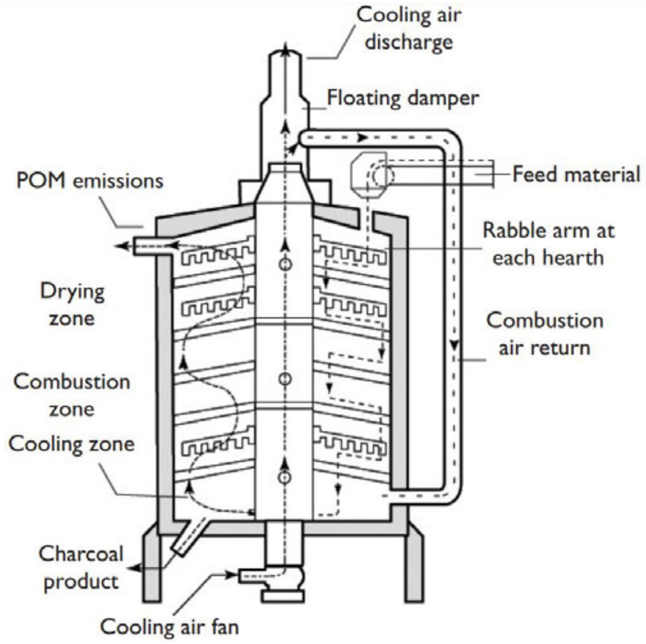


Figure 21: Continuous multiple hearth kiln (Lehmann & Joseph 2009)

Drum Pyrolysers process the char by moving biomass axially through a rotating sealed drum that is externally heated. Heat energy can be harnessed from the produced syngas, supplied energy source or a combination of both.

Screw Pyrolyser – Operates in a similar fashion to a drum pyrolyser, however biomass transits through the reactor with the assistance of an auger. The advantage of a screw type pyrolyser is the ability to have small scale pyrolyser with continuous feed characteristics

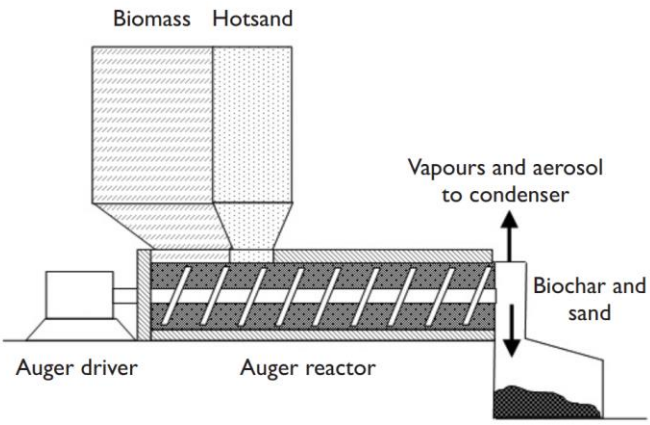


Figure 22: Screw pyrolyser with heat carrier (Lehmann & Joseph 2009)

Fluidized Bed pyrolysis is ideal for granular feedstock material and applies hot gas from a combustion chamber at high velocity through the feedstock particles which cause it to levitate and behave like a fluid. This method is more complex than others discussed here however the advantages include greater uniformity in thermal carbonisation of the biomass.

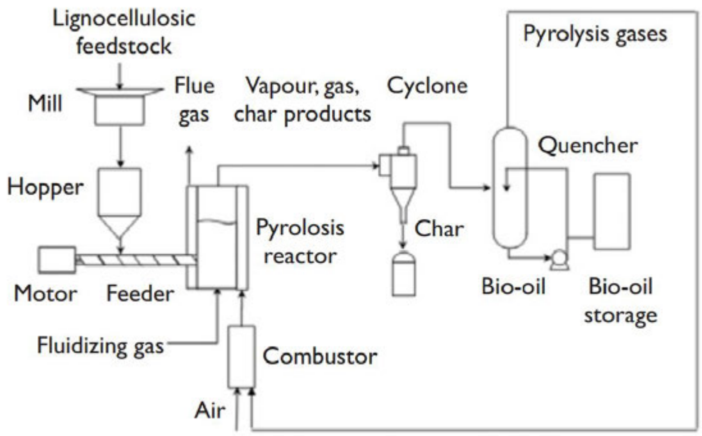


Figure 23: Fluidized-bed fast pyrolysis reactor (Lehmann & Joseph 2009)

Gasification Systems operate using a process that follows pyrolysis, with the aim of releasing more energy rich syngas which can be used as an energy source. Char produced under the gasification process typically contains 10%-12% of the original biomass weight and 25%-30% of the original carbon.

The process of transforming biomass to char is relatively simple and many hobbyists achieve reasonable quality and quantities of char with little more than a large steel drum. However, simple arrangements are less energy efficient and without the ability to regulate the peak temperature, the char properties are likely to be inconsistent leading to the production of a charcoal/biochar mixture with varying properties.

To overcome some of these inefficiencies there are some areas that requires additional focus. Typical pyrolysis of biomass can produce char residue at approximately 20% of the original feedstock mass. Studies have shown that by increasing the pressure during slow pyrolysis of cellulose-based feedstocks nearly doubled the char yields in most cases (Antal & Grønli 2003, p. 1623-1624).

Heat can be generated from multiple sources and is critical in the pyrolysis process. Any heat losses decrease the efficiency of the pyrolysis process. Insulation of the reactor and any other heated chambers could provide a suitable means to improve the overall system efficiency.

Designed to target the production of syngas as a fuel alternative, gasifiers saw wide use and success during World War II as an alternative to automobile fuel. Unlike in pyrolysis, gasifiers introduce oxygen to the reactor to assist in biomass combustion.

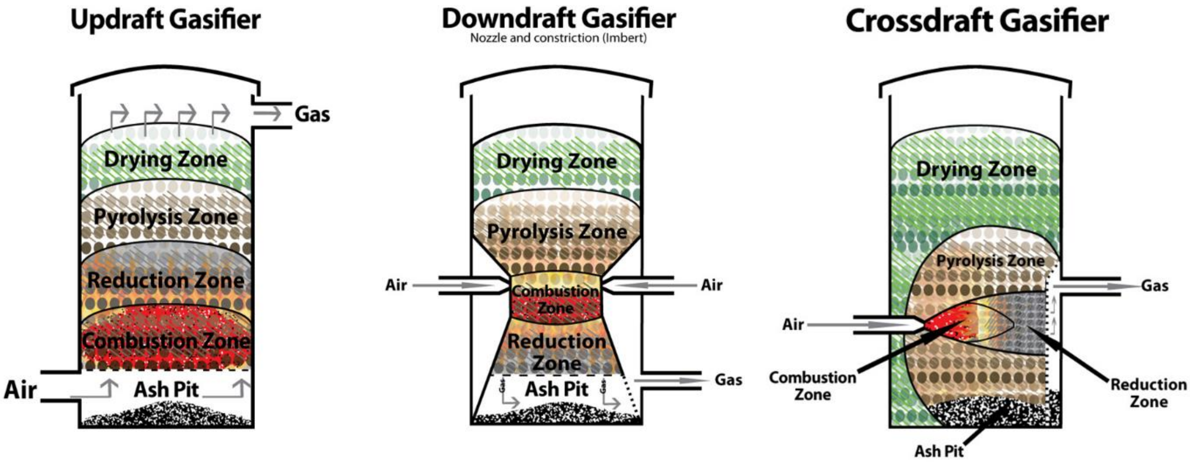


Figure 24: Updraft, Downdraft and Crossdraft gasifier varieties (All Power Labs 2022b)

Table 1: Gasifier types

Basic Types	**Operation**	**Pros**	**Cons**
Downdraft	The upper portion acts as a silo to funnel feedstock downward to the reactor. Numerous air nozzles arranged radially direct air to the combustion region releasing gas from the biomass.	Self regulates to maintain a consistent levels of char. Formation of ash below the air nozzles acts as an insulator	High rate of tar production Not suited for fuels with high volatile material
Updraft	Biomass enters from the top of the system with air entering from beneath to react at the base of the gasifier region.		Temperatures need to be regulated where the air enters the gasifier to prevent slagging of ash on the grate
Cross draft	High velocity air enters through a single nozzle to create increased circulation of hot gases across biomass	Simple light design Produces low tar-gas Fuel and ash act as an insulator	Prone to slagging with biomass with high ash content Suitable only for low tar fuels Prone to bridging and channelling for biomass with lower flowability

Hydrothermal Conversion Systems uses the reaction of an organic material in the presence of a fluid under high temperature and pressure. It can be categorised further into three different processes, Hydrothermal carbonisation (HTC), Hydrothermal liquefaction (HTL) and Hydrothermal gasification (HTG) producing hydro-char, liquid bio-crude and syngas respectively. These processes favour biomass with a high water content such as sewage, food waste and aquatic biomass as fluid forms the reaction medium required for conversion.

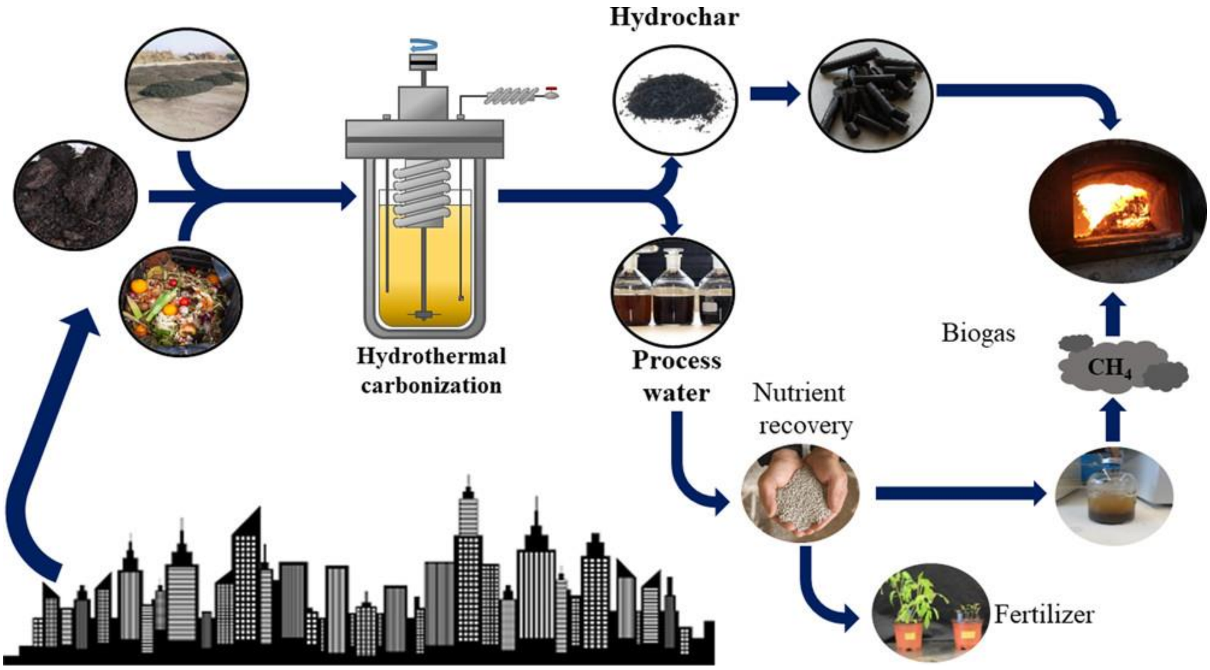


Figure 25: General Hydrothermal carbonisation process (MagNews24 2021)

Chapter 3 Design Requirements

Design requirements will not only outline key elements that need to be addressed in the design, but it also ensures there is a means to verify the final design to identify where the design is compliant and where further design effort is required.

The design requirements in Appendix E have been sourced from Australian regulatory and legislation requirements, standards, industry best practice and any requirements the designer identifies is required to ensure the safety of personnel and the environment.

Chapter 4 Design Methodology

4.1 Introduction

The methodology employed in this project is categorised broadly under three phases:

1. Research Phase
2. Design Phase
3. Design Analysis

The research phase is critical in developing a sound understanding of the impacts of climate change on the agriculture industry and to identify suitable measures to mitigate these impacts. The design phase requires inputs from the research phase to direct the solution parameters and desired production process. This stage of the project aims to develop mechanical concept designs for assessment and selection of the final design. The final stage in this project is the design analysis stage which provides a means of validation of the final design against technical, socio-economic and financial constraints.

4.2 Research Phase – Literature Review

Degraded soils and their causes - There are multiple drivers of soil degradation across the globe however land management practices and anthropological climate change are causing significant environmental issues. These drivers along with their impact on soil properties will be investigated to ensure that there are sufficient indicators for use during the design validation phase.

Benefits of biochar - Biochar properties and application methods will be researched with the intent on identifying specific issues to be addressed as part of this project, but also propose new and novel opportunities across multiple industries. This research is critical in ensuring that the final design can address the project problem identified.

Biochar production methods - The production and process for manufacturing biochar is as varied as the final product quality. This step will assist in identifying a suitable method for producing biochar of a suitable quality, quantity and with the properties appropriate for the desired application. Research of biochar production methods will also assist in establishing the system design components and subsequent design requirements.

Identify suitable feedstock from agricultural waste - In conjunction with the production method, research will be required to identify and select a sustainable feedstock for the production of char. Once identified, the feedstock will influence the char properties of the end product and the necessary production method.

4.3 Design Phase

4.3.1 Introduction

The design phase will draw on the requirements established in chapter 3 for the final design which will help shape the scope of the mechanical design including general system requirements, derived from state and federal legislation, biochar and agriculture governing bodies, Australian Standards and anticipated operating conditions based on experimental data. With a comprehensive set of design requirements, the system can be tailored to meet regulatory and end-user requirements.

During the concept design phase, the system design will be broken down into subsystems, components and functions. Once the elements of the overall system and its interfaces are understood, their function, requirements and specifications can be assessed for selection during the detailed design phase.

This projects design phase focuses on the mechanical design with consideration for the electrical aspects which is largely centred on the monitoring and control systems. Refer to Chapter 6.3 for further information.

4.3.2 Design Requirements

Regulatory and Legislative Requirements

The design must meet all regulatory and legislative requirements in order to achieve a suitable design solution. Currently the biochar industry is not heavily regulated and as such, local and international industry bodies such as Australia New Zealand Biochar Industry Group (AUS/NZ) International Biochar Initiative (US) and European Biochar Certification (EU) will be used to guide regulations in the production of biochar. Regulatory requirements for Australian machinery are in a mature state and will be referenced from Australian legislation and Acts. In the absence of specific regulation, this project will refer to Australian and New Zealand Standards where available.

Environmental consideration needs to be given to minimising or mitigating any negative environmental impacts that may arise from the use of the final char product, this includes gaining approval for the treatment of agriculture waste, chemical composition of char and emission standards.

Environmental Requirements

Atmospheric pollutants can be generated from the burning of waste organic material in an uncontrolled manner when incomplete combustion occurs. It is therefore necessary to identify potential pollutants and a means to mitigate them. The EPA, through The Clean Air Regulations 2021 sets the standards for the emission of designated pollutants and concentrations levels for a given sampling period and it identifies six key air pollutants for which air quality standards are set by:

1. Carbon Monoxide (CO)
2. Nitrogen Dioxide (NO_2)
3. Sulfur Dioxide (SO_2)
4. Lead
5. Photochemical Oxidants (O_3)
6. Particles smaller than 10 microns (μm) in diameter

The likely contributor in the production of syngas is carbon monoxide however the combustion reaction may contribute additional pollutants particularly NO_2. Nitrogen Dioxide can be treated post combustion using selective catalytic reduction or oxidisation cycle technologies which can address both CO and NO_2 levels.

Table 2: Air National Environment Protection Measure (NEPM) standards and goals

Pollutant	**Averaging period**	**Maximum concentration standard**
Carbon monoxide	8 hours	9.0ppm
Nitrogen dioxide	1 hour	0.08ppm
	1 year	0.015ppm
Photochemical oxidants	8 hours	0.065ppm
Sulfur dioxide	1 hour	0.075ppm
	1 day	0.02ppm
Lead	1 year	0.50μg/m^3
Particles <10 μm	1 day	50μg/m^3
	1 year	25μg/m^3
Particles <2.5 μm	1 day	20μg/m^3
	1 year	7μg/m^3

Land pollutants can arise from the introduction of char to the environment that contains traces of volatiles. This is likely to occur if the biomass hasn't reached the required temperature to release all volatile gases and tars during the carbonisation process. Through monitoring and process control of char production, the removal of volatile substances should be sufficiently managed.

Component Requirements

Each component or subsystem will need to be capable of safe operation and maintenance under a variety of environmental conditions such as high temperatures, adverse weather and duty cycles as well as meeting the systems operating specifications. To assist in identifying these requirements, the system will be broken down into subcomponents identified during concept design phase.

Material Requirements

The system will be exposed to a variety of thermal and environmental conditions, and it is important that these are considered in the material selection process.

Thermal – During normal system operation, it is anticipated that a continuous temperature as high as 1000°C will be reached inside the reactor and similar temperatures expected in parts of the hopper. Elsewhere the temperature is expected to be much lower and is not a primary design consideration.

Strength – The main strength consideration in the design is in the support structure which will need to support the static and dynamic loads of the system.

Corrosion resistance – It is likely that this design, in its current form, will be exposed to outdoor environmental conditions where a corrosive environment is a likely to occur. Material selection will need to include materials that are either resistant to corrosion or have corrosion protection measures applied. Material properties for carbon, alloy and stainless steels are listed in Appendix F.

Feedstock entering the system needs to be of a homogeneous in size (approx. $25mm^2$), material and moisture content to ensure adequate flowability, process temperatures and quality are maintained.

Functional Requirements

The functional requirements are largely designer imposed requirements with the intent of designing a pyrolysis machine with particular features and capability to ultimately aid in a final design that exceeds the needs and expectations of the end user. An initial function requirement selected was for the system to be batch operated with a single batch capacity of 1000L and capability to process two batches in an eight hour timeframe.

4.3.3 System Architecture

The system architecture below provides a basic system arrangement which will assist in identifying each of the subsystems and how they integrate to the system.

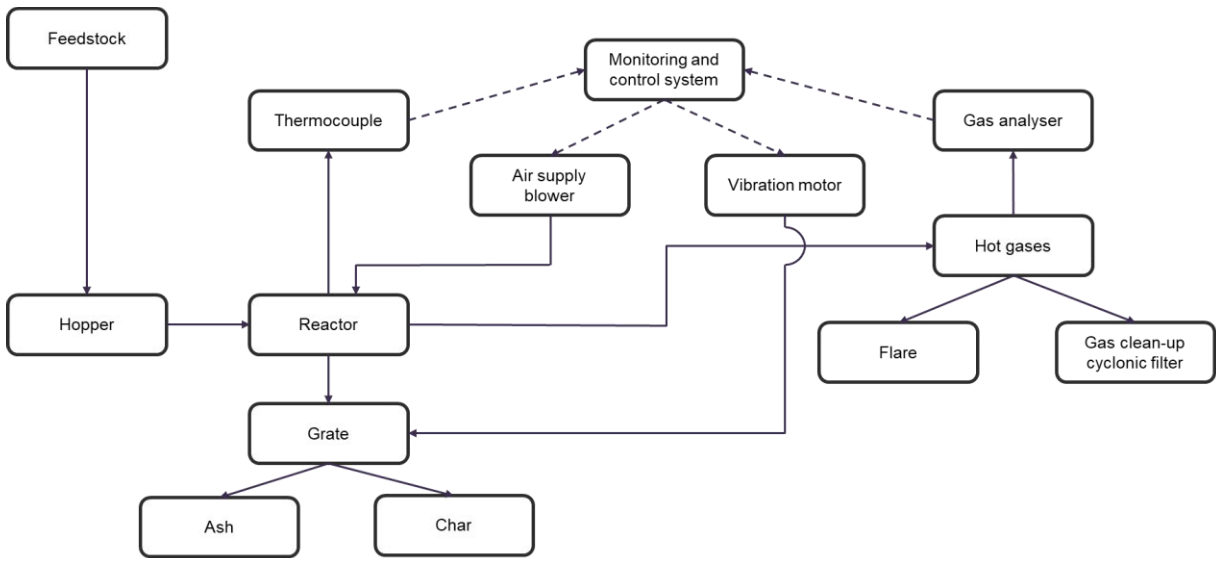


Figure 26: System Architecture

4.3.4 Feedstock Considerations

Feedstock properties and selection can have considerable impact on the carbonisation process required to attain specific char quality. Feedstock selection varies in size, moisture, volatiles, ash, fixed carbon physical and chemical composition. These variations have a significant impact on the thermal and chemical reactions during the carbonisation process.

The effect of water or moisture in the feedstock reduces the heat recovery and combustion efficiency of the process as more energy is required to remove moisture below the operational 5-10% threshold for most gasifiers and pyrolizers. While the design of a pyrolysis machine to produce char isn't largely reliant on a particular feedstock, this project will aim to design an 'all-rounder' pyrolyser with the capability of producing chars from various feedstocks across a range of temperatures, heating rates and holding times.

Ash contained in feedstock does not provide any benefit to the to the overall process and can negatively affect system components as it melts in a process called "slagging". Feedstocks with high ash content are better suited for carbonisation in a fluidised bed gasifier.

Volatiles contained within the feedstock can be released as syngas and bio-oils through the thermal decomposition process. This can offer additional energy to produce heat or to fuel an internal combustion engine.

Fuel shape, bulk density (weight/volume), angle of repose and feeding characteristics determine if the system requires feed introduced with mechanical assistance such as stirrers, shakers and augers or under the influence of gravity.

The flowability of feedstock is critical during the design phase to promote the movement biomass from the hopper to the combustion region. Consistent feedstock size is required to adequately design a system capable of handling the biomass through the entire process ensuring flowability. Inconsistencies in feedstock size and geometry can result in various flow issues as depicted in Table 3.

Table 3: Hopper Flow Modes (All Power Labs 2022c)

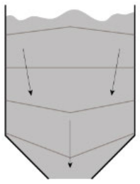
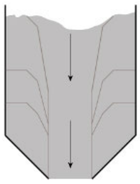
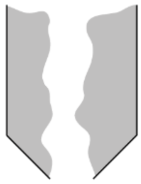
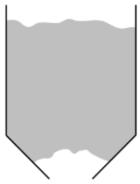
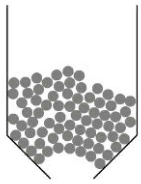
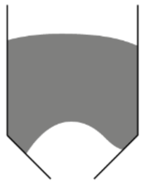
Mass Flow	**Funnel Flow**	**Rat-holing**	**Bridging**	**Interlocking Arch**	**Cohesive Arch**
					

Table 4: Waste agricultural feedstock properties

	Moisture content	Density (kg/m^3)	Composition (%)			Higher Heating Value (MJ/kg)	Produced per year[1]
			Cellulose	Hemicellulose	Lignin		
Macadamia Shell	-	680[5]				21.01[2]	
Sugar Cane Bagasse	9.4[2]	68[4]	40[2]	30[2]	20[2]	18.9[2]	30.3 million tonnes, 355k Ha
Coconut Shell (Dried)	8[3]		26.6[3]		29.4[3]	20.8[2]	
Wheat Straw			30[2]	50[2]	154[2]		
Cotton Stubble			35[2]	25[2]	35[2]		
Cotton Gin		390	64[4]	64[4]	18[4]	16.6	
Cow Manure	13.08[2]					15.93[2]	2.4 million
Poultry (chicken) Manure							123 million
Pig Manure							2 million

[1] (Australian Bureau of Statistics 2021b)
[2] (Thakur & Thakur 2014, p. 105)
[3] (Husseinsyah & Mostapha 2011, p. Page 88)
[4] (Jordan, Easson, Cheng & Condon 2022, p. 2.)

Table 5: Biochar characteristics for different temperatures (Tomczyk, Sokołowska & Boguta 2020, p. 194-196.)

Feedstock	Pyrolysis Temp (C)	Yield (%)	pH	Specific Surface Area (m^2/g)	Volatile Matter (%)	Ash (%)	CEC (cmol/kg)	Total Carbon (%)
Dairy Manure	100	97	8	1.8	-	37	-	36.8
	200	58	6.8	2.7	-	44	-	31.1
	350	27	9.2-10.5	1.6-7.1	53.5	24.2-62	-	25.2-55.8
	500	25	10.5	13	-	95	-	1.7
	700	-	9.9	186.5	27.7	39.5	-	56.7
Chicken Manure	300	-	8.1	-	23.9	34.8	137.6	-
	350	69.7	9.7	-	36.9	52	-	31.2
	450	63	10.2	-	30.6	55.3	-	27.2
	500	-	10.6	-	11.9	38	81.4	-
	750	55.9	11.7	-	26.5	56.4	-	24.7
Pig Manure	300	-	7.8	-	31.3	50.3	35.6	-
	400	-	-	15.6	19.1	46.5	-	44.1
	500	-	8.2	-	6.5	73.9	32.7	-
	600	-	-	15.9	15.1	50.3	-	42.3
Sugarcane Bagasse	350	37.5	7.2	-	35	1.9	-	74.7
	400	31.6	7	0.8	-	-	3.8	-
	450	33.2	8.8	-	24	2.1	-	81.6
	475	-	6.6	259	-	12.1	122	57.3
	600	22.9	7.7	14.1	-	-	4.2	-
	750	26.9	9.7	-	7.7	2.2	-	90.5
Corn Stover	300	66.2	7.7	3.2	54	5.7	-	45.5
	400	17-37.1	7.2-8.8	3.1-3.2	45.5	12.5-32.8	-	57.3-64
	500	29.2	9.8	4.6	33.8	18.7	-	64.5

4.3.5 System Specification

The overall system specification and capacity can be determined based on the properties of a given feedstock and the process followed during the carbonisation process. Key specifications include Syngas production, energy value and char fixed carbon yield which can be used to determine the energy available in the gas for heating or fuel and the quantity of char available in the feedstock to estimate production quantities and system efficiency.

Mass balance: $$m_{feedstock,in} + m_{air,in} = m_{char,out} + m_{i,gas,out}$$

Syngas Production: $$m_{gas}(kg) = Flowrate(m^3/s) \times \rho_{gas}(kg/m^3) \times time(sec)$$

Syngas Energy value: $$Q_{gas,out}(kJ) = m_{gas}(kg) \times HHV_{gas,out}(kJ/kg)$$

Char production: $$Char_{yield}(\%) = 100 \times \frac{mass_{char}}{mass_{biomass}}$$

Heat produced from Biomass: *HHV=[34.1*C + 132.2*H + 6.8*S - 1.53*A – 12.0*(O+N) kJ/g*

Oxygen required for complete reaction $$m_{O_2} = Y_C \frac{M_{O_2}}{M_C} + \frac{Y_H}{4}\frac{M_{O_2}}{M_H} + Y_S \frac{M_{O_2}}{M_S} - Y_O$$

Where:

$m = mass$

$\rho = density$

$Q = flow$

$HHV = Higher\ Heating\ Value$

M_i $is\ molecular\ mass\ of\ element\ i$

Y_i $is\ the\ mass\ fraction\ of\ element\ i$

4.3.6 Concept Design

Concept Principle

The concept for design will leverage characteristics of both a gasifier and pyrolyser. Biomass will enter the reactor where it will initially be combusted using a fuel accelerator. Air will be introduced into the reactor via a blower to aid the combustion process until sufficient heat is generated for pyrolysis to occur. During the initial stages, gas vapours containing moisture and volatiles will be processed through the flare to minimise atmospheric pollutants. As the system approaches the desired temperature, the blower air supply is reduced and then it and the flare are isolated from the system. Temperature in the reactor is maintained (increased) with air supplied from the blower. Once the required residence time has been achieved, the vibration motor will energise forcing the upper biomass to compress and ‘grate’ the brittle char against the reactor grate.

The concept design will be grouped into stages outlining their purpose and design considerations. These stages are:

Stage 1 Delivery System – manages the transfer of biomass through the system

Stage 2 Reactor Assembly – facilitates the carbonisation process

Stage 3 Hot Gases – addresses the management of gases produced during combustion

Stage 4 Control System – monitors and controls the carbonisation process

Stage 5 Power System – supplies power to ancillary systems

Stage 1 Delivery System

The feedstock delivery system broadly categorises the transportation of feedstock through the pyrolysis system. It will consist of a bulk storage chamber from which feedstock can be introduced into the reactor assembly. It needs to have a 1000 litre capacity for feedstock to ensure the system can operate for a period of time while minimising user input.

Hoppers serves to store and funnel the feedstock into the system combustion region. The restriction nozzle at the base of the hopper needs to be angled sufficiently to account for feedstock characteristics that may otherwise inhibit flow characteristics. In addition, the nozzle throat must be sized to prevent the formation of thermal inconsistencies in the biomass. Failure to account for feedstock flowability in this region can result in Rat-holing where the outer feedstock boundary ceases to flow correctly resulting in inconsistent flow characteristics and potentially enabling the combustion region to propagate into the hopper. The hopper is exposed to continuous high temperature ranges which make it susceptible to

Vibration Motor assists in the flowability and eventual extraction of solids through the system and aides in the prevention of biomass bridging and other similar adverse conditions. The vibration force is generated by rotation of a shaft with attached unbalanced mass.

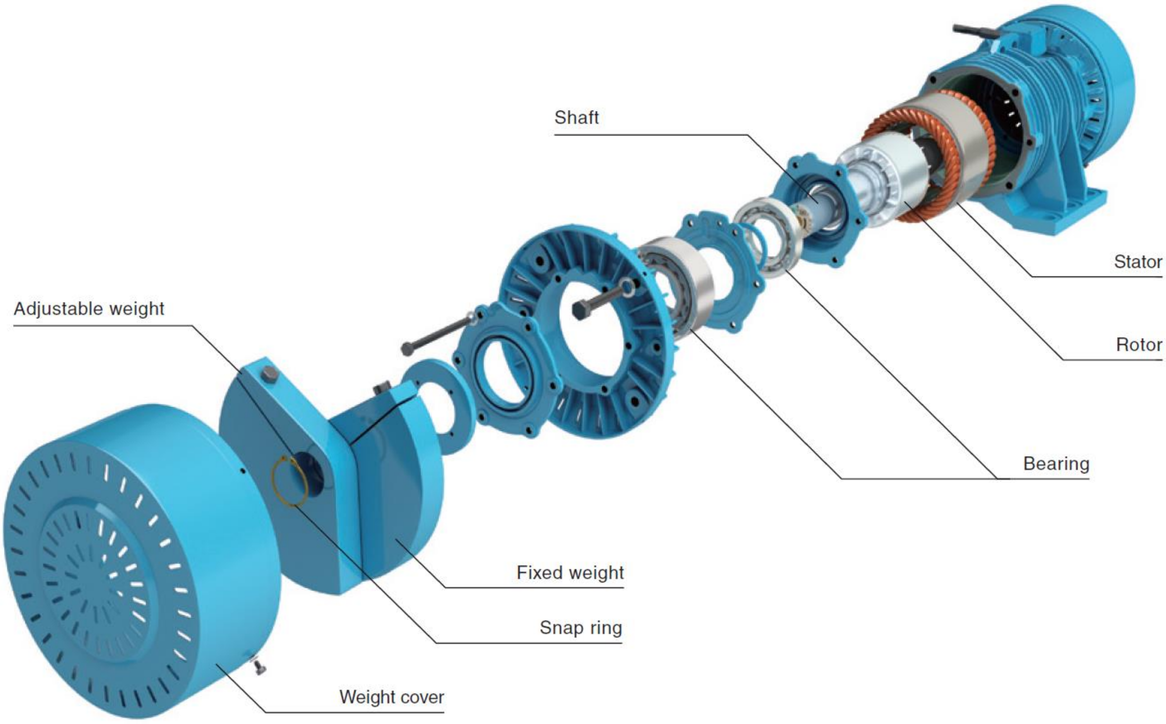


Figure 27: Vibration motor general construction (URAS Techno 2021)

To determine the sizing requirements of the motor, the feedstock and system mass needs to be calculated:

Stage 2 Reactor Assembly

Drying is the first stage of the reactor and largely occurs in the hopper. This stage aims to reduce the moisture content in the feedstock to assist the pyrolysis process. Ideally waste heat from the combustion/exhaust process could be directed to increase the temperature of the drying compartment.

$$Heat \rightarrow Biomass\ (C, H, O) \rightarrow H_2O$$

Pyrolysis occurs further into the reactor as the heat increases from the combustion section. This phase requires heat to perform the carbonisation process, Heat will initially be sourced from the direct combustion of biomass until such time that the system produces sufficient syngas to become self-sustaining. To ensure the system conserves heat energy, the reactor will need to be insulated to retain heat for the carbonisation of feedstock. Where heated exhaust, or by-products are removed from the reactor, the design will aim to capture heat losses in such a way as to improve the overall efficiency.

The reactor will require a chamber that is of a material capable of withstanding high thermal conditions. Control systems will monitor and regulate chamber temperature, holding times and extraction system to remove all solid, liquid and gaseous by-products. Temperatures are anticipated to reach up to 1000°C in the reactor lining.

$$Heat \rightarrow Biomass\ (C, H, O) \rightarrow Char + Tar + gas$$

Combustion section which occurs at the nozzle, promotes the oxidisation of the biomass with the addition of air to produce hot gas for pyrolysis and drying and charcoal as energy for the reduction zone.

$$Heat + O_2/air \rightarrow Char + Tar + gas \rightarrow H_2O + CO_2$$

Nozzle

The restriction nozzle performs two functions; to direct biomass to the combustion region while simultaneously concentrating the gases produced during combustion in the form of CO_2 and H_2O and reduces them into combustible CO and H_2 when exposed to hot coals in the reduction section.

Reduction region promotes further release of syngas from the char and the addition of water vapor increases carbon monoxide and char porosity.

$$H_2O + CO_2 \rightarrow Char \rightarrow H_2 + CO$$

Stage 3 Waste Management

Waste gas and toxic emissions, tars and ash are an unwanted by-product of the system and need to be managed effectively. Some waste can be controlled as part of the system operation while other wastes will require routine inspection and cleaning.

Gas treatment Gases originating from the combustion stage pose both a physical and chemical concern. Physically these gases contain a mixture of carbon, ash and tar which if left untreated can create blockages in the pipe network resulting in reduced effectiveness of system operation. Care must be taken to manage the cooling rate of gases which are prone to condensation leading to the collection of tar and moisture in the system pipe network. Preheating the air prior to combustion leads to less tar production which is desirable. Post reduction process, ash and carbon contaminates can be removed by passing the raw gas through a cyclonic filter to remove the larger particulates or a gas scrubber if greater filtration is required.

Chemically, the gas is made up of carbon monoxide and hydrogen with the potential for traces of carbon dioxide to be evident also. Correct sizing of the restriction nozzle will greatly assist in the conversion of carbon dioxide and water molecules (reduction) to hydrogen and of carbon monoxide.

Generic cyclonic style filters use centrifugal forces to separate as much as 80% of the coarser particles with further cleaning available through a gas scrubber. They offer a durable maintenance free option to gas filtration. Stairmand high efficiency cyclones have shown effective filtration of 98% of particles averaging 1.6µm (Akhbarifar & Shirvani 2019, p. 483-492).

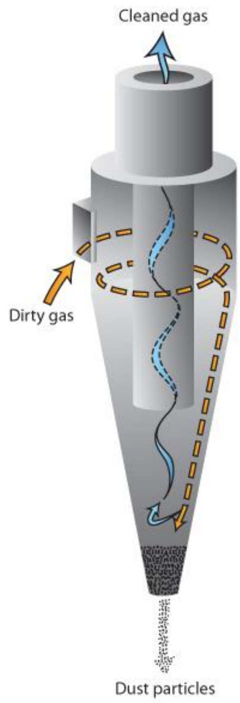


Figure 28: Cyclone filter principle (Redecam 2018)

The efficiency of a cyclonic filter can be approximated by:

$$N_e = \frac{1}{H}\left(L_b \frac{L_c}{2}\right)$$

Where:

$N_e = number\ of\ effective\ turns$

$H = height\ of\ inlet\ duct$

$L_b = cylinder\ height$

$L_c = cone\ height$

Gas scrubbers use a fluid and filters to collect undesirable particles present in the gas stream and is commonly used in series with a cyclonic filter system. It is critical that water remains in the liquid phase as it can vaporise and lead to lower effectiveness of the scrubber. Therefore, gas inlet temperature should not lead to a phase change of the liquid medium. The use of scrubbers is highly desirable if the contaminants pose a risk to the system for which it will be used such as an internal combustion engine.

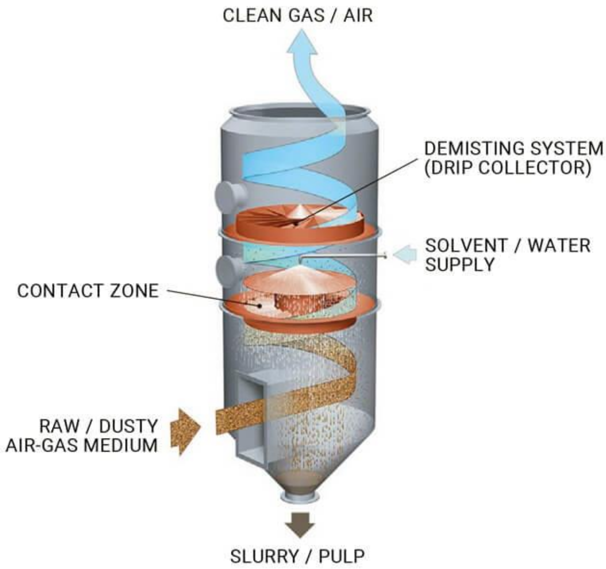


Figure 29: Round-section tower-bodied whirl-type foaming filter (PZGO LLC 2022)

Flare management of combustible gases, which are intermittently present on start-up, can be neutralised through combustion, a process known as flaring. Industrial flaring systems have various types dependent on the application which are often quite complex. Given the size of this design and the desire to reduce complexity, a simplified design will be incorporated.

Vertical Flares – gas is delivered to the top of a chimney like structure where it is combusted.

Steam assist flares are commonly used in large scale refineries and chemical plants. Their design permits combustion of gas with the injection of steam into the combustion region to increase turbulence and promote the mixing of air resulting in less smoke production.

Figure 30: Steam assisted flare (Encore Combustion 2020)

Air assist flares are not typically used on larger gas production plants as it is less economical and is often used when steam is not available. It operates by increasing the air fuel mixture in a similar manner to steam assisted flares with the intention of reducing smoke.

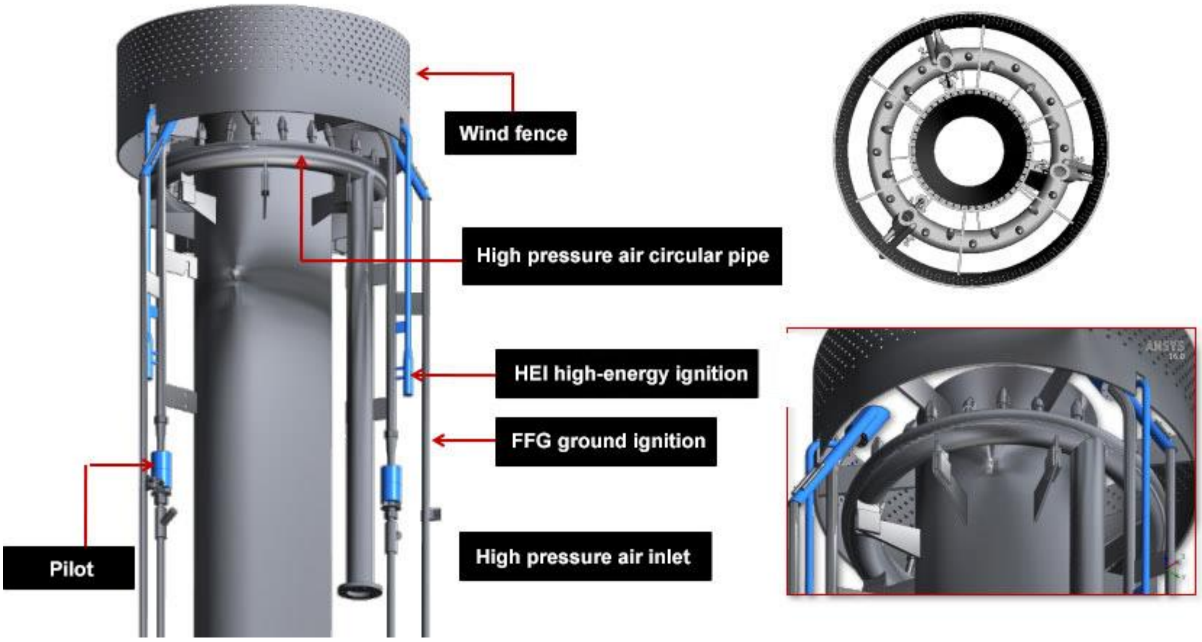


Figure 31: Air assisted flare (Jiangsu Sunpower Technology 2018)

Enclosed ground flares are located the ground surface and are designed with the burner contained inside an insulated shell thereby reducing noise, luminosity and heat radiation. They are reliable and efficient however, they are best suited to continuous gas flows.

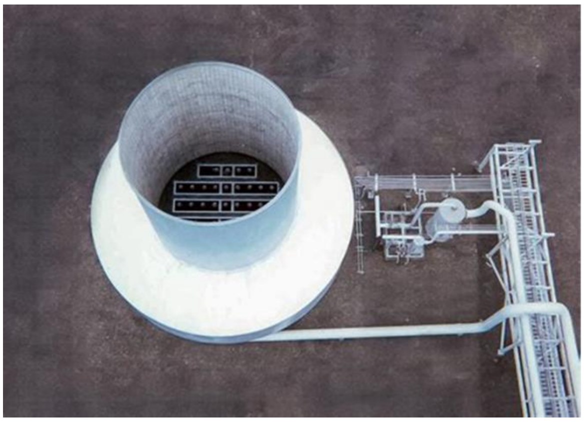


Figure 32: Enclosed ground flares (Zeeco 2022)

Pit/ground flares are situated at ground level and lined with a refractory material. The simplicity of ground-based flares make them more economical initially and over the life of the system than that of vertical flares however they require a greater footprint to build and given the hazard they pose, require an exclusion zone.

Figure 33: Pit flare (The Baltimore Sun 2013)

The main design considerations identified for flaring is it must incorporate a mixing chamber for gases to mix with air to enable combustion, have an ignition source and that it does not pose a hazard to personnel or the environment.

Ash will collect in the lower region of the system, and it is expected ash will accumulate on any surface or component that is exposed to combustion gases. These items will require periodic removal and cleaning to maintain system operation and efficiency.

Stage 4 Monitoring and Control Systems

Management of the system is required to promote the desired operating parameters such as temperature control and residence times. Automation of the entire process is key and to achieve this, temperature and residence time parameters need to be proven in field trials to provide a proven process schedule for each given feedstock. Only the general control system components and functions will be discussed in this document. Greater expertise in electronic and electrical design is required to complete the control system.

Monitoring system

Operation with temperature sensors and a gas analyser, are required in the reactor to ensure that a suitable heating schedule and residence time is adhered to in order to produce char of a desired specification. Data from these sensors will feed into a programmable logic controller

Temperature sensor selection needs to consider the systems operating temperature range, sensor accuracy and stability, size and cost.

Thermistors – Consist of an epoxy coated sensing element, measures temperature by sensing the change in electrical resistance.

Thermostats are a contact type sensor comprising of two dissimilar metals where the difference in thermal expansion of the metals creates a physical change that can be measured.

Resistive Temperature Detectors (RTDs) operate in a similar way to thermistors, with a much larger temperature range, fast thermal response times and are close to 10 times more accurate than thermocouples. RTDs are available in copper, nickel and platinum sensing elements each with its own temperature ranging from -200°C to 260°C, -80°C to 260°C and -200°C to 850°C respectively.

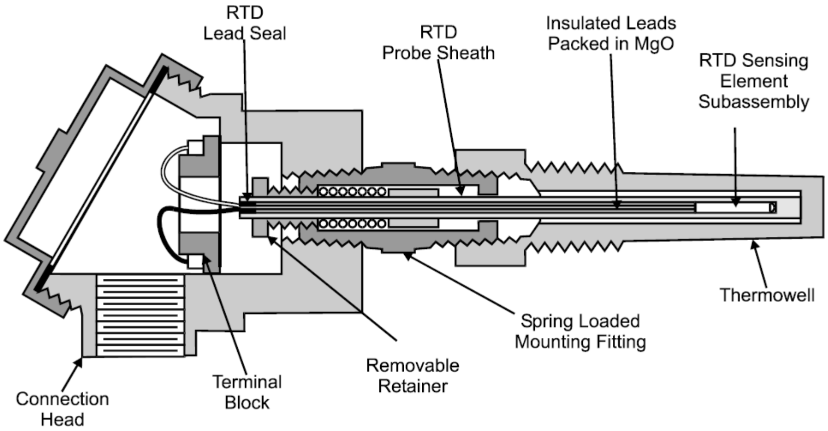


Figure 34: Resistive temperature detector construction (AutomationForum.co 2020)

Thermocouples consist of two connected metals with temperatures creating a thermal gradient in each metal that creates a current that can be measured. Thermocouples are available in a wide range of temperature applications and are quite sensitive, often having a faster response to thermal changes than RTDs.

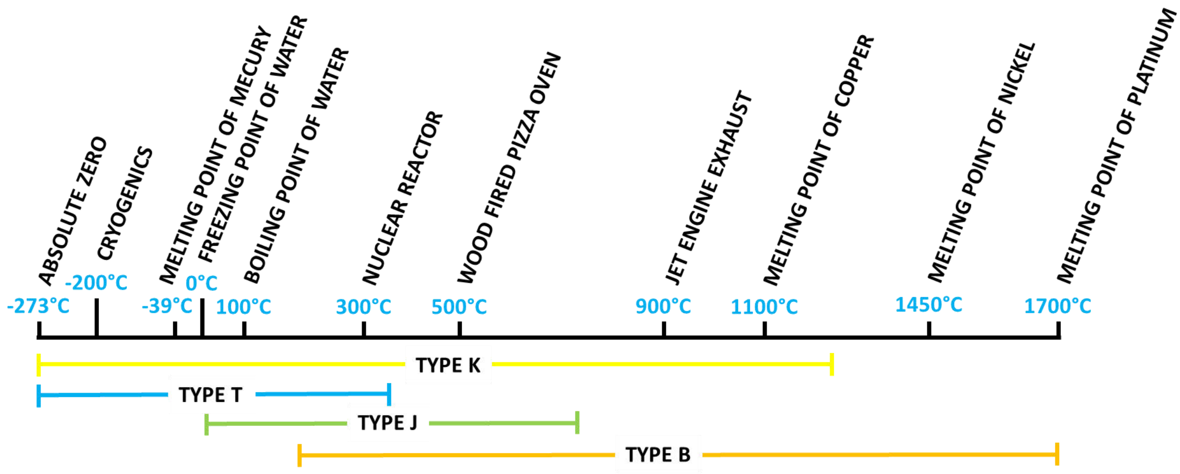


Figure 35: Thermocouple operating range

Gas Analyser will need to measure the type and quantity of a gas being produced from the reactor to assess the state of thermal decomposition of the biomass and to understand the potential for undesirable gas emissions into the environment.

Thermal Conductivity analysers compare the gas sample in the measuring chamber to a reference gas to determine its thermal conductivity. A circuit runs through each chamber which heats the surrounding gas and subsequently changes the conductivity of the gas. Thermal conductivity analysers typically get combined with other analyser types to provide more accurate analysis.

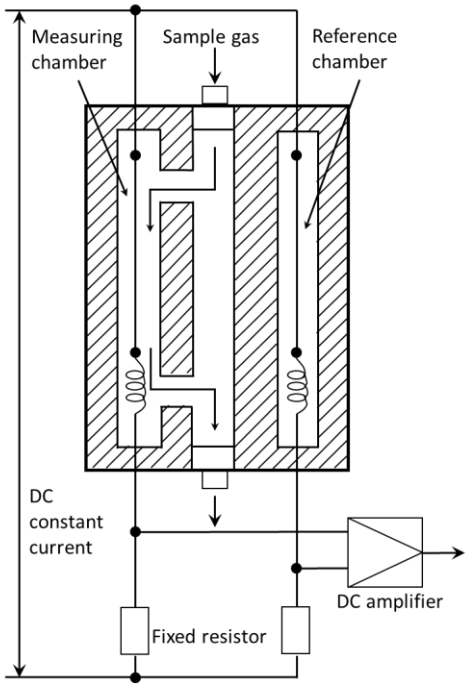


Figure 36: Thermal conductivity gas analyzer (Fuji Electric 2016)

Electrochemical analysers are designed to measure the concentration of a specific target gas. They typically consist of a sensor and a reference electrode submerged in a electrolytic fluid. Gas passes through the fluid causing an electrochemical reaction resulting in an electrical output proportional to the concentration of the target gas.

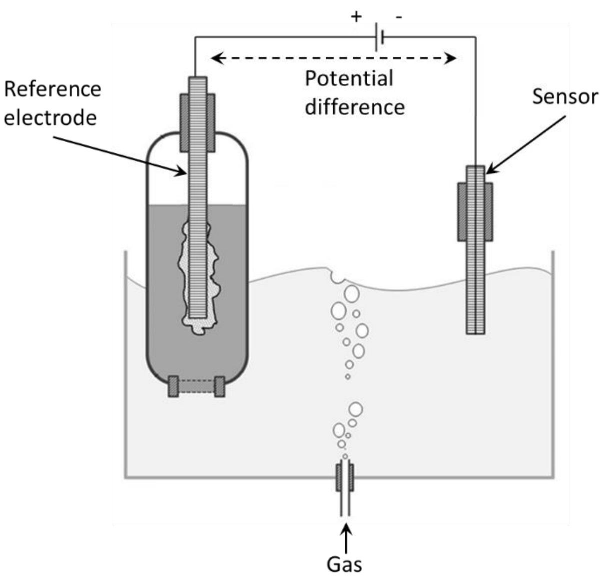


Figure 37: Principles of the Oxygen Cathode (Yartsev 2020)

Infrared analyser work by directing infrared light at a gas sample, toward an optical filter and into a light detector. Gas molecules absorb the light and through variations in wavelengths, infrared sensors can detect gas concentration in the surrounding atmosphere, IR analysers can analyse a wide range of gases including carbon dioxide, carbon monoxide, methane and sulfur dioxide.

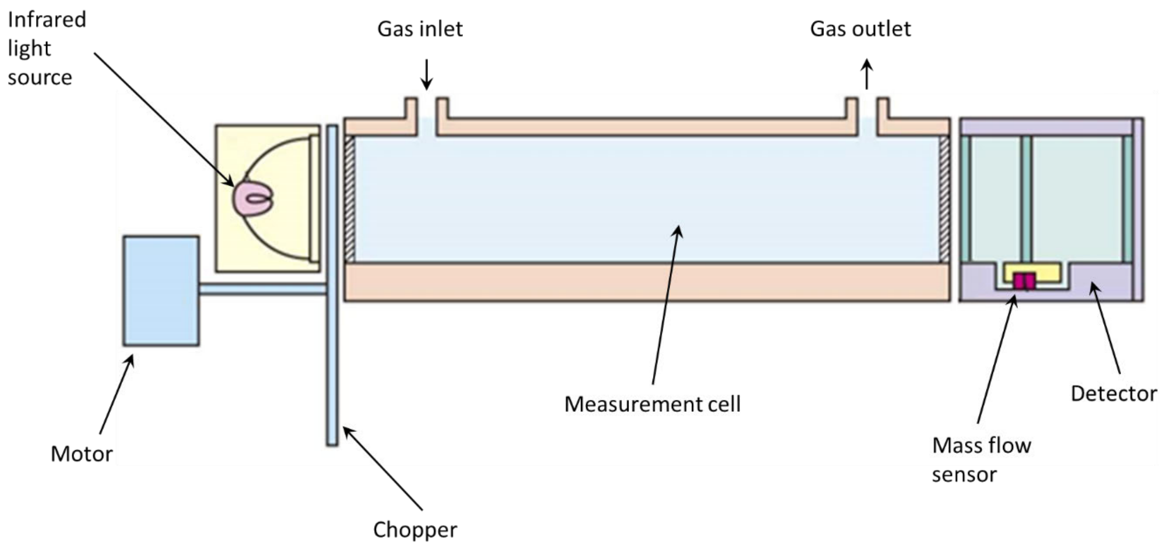


Figure 38: Simple beam nondispersive infrared (NDIR) principle (Fuji Electric 2022)

Control System

The control system serves in conjunction with the monitoring system to produce char of a desired specification by modulating air flow to the combustion chamber and sequencing of each process. Monitoring sensors feed into the control system which will be programmed to execute a predetermined set of commands for a given schedule. Some elements of the systems process will require manual input, it is desirable to automate as many of the processes as possible to reduce user input. These processes include automation of the blower and vibration motor on/off cycles based of input data from the thermocouple, gas analyser and internal timer. The general control process will need to address three conditions:

Case 1 – Unburnt fuel in the reactor

Case 2 – Burnt fuel in reactor

Case 3 – Reactor empty

Blowers or air pumps provide the necessary airflow for the thermal decomposition of the feedstock. Improper supply of air to the reactor will lead to failure of the required process, too much air will lead to complete combustion of the biomass, too little will result in a char product containing residual volatiles.

Key considerations when selecting a blower include airflow, static pressure, power requirements, cost and if the blower will push air or pull air from the system. Typically, more power is required to pull gas than to push air through a system due to the differences in mass. Suction blowers also need to be suitable for high temperatures.

Systems that push air create a situation where gases such as carbon monoxide can leak whereas systems pulling air tend to operate below atmospheric pressure with leaks presenting a risk of explosion.

Since gasifiers require greater flow rates, and to provide greater flexibility in the application of the design, the blower will be sized to suit a downdraft gasifier.

Research by Abubakar, Oumarou & Oluwole (2018) identified that on average, a kilogram of biomass produces 2.5m^3 of syngas while consuming 1.5m^3 of air for combustion. While there is no intent for complete combustion, this research will form the basis for the maximum air requirements required for biomass carbonisation.

Considering the current design is configured for batch processing only and to increase productivity, it is determined that a minimum of two batches shall be processed in an eight hour day. For the 1000L hopper capacity using macadamia nutshell with 680kg/m^3 mass:

$Volume\ (biomass)\ required$:

$$2 \times Hopper = 2000L = 2m^3$$

$Maximum\ air\ required\ for\ combustion$:

$$\frac{1.5m^3}{1kg} \times 2m^3 \times 680\frac{kg}{m^3} = 2040m^3\ per\ day$$

$Maximum\ air\ production\ rate$:

$$\frac{2040m^3}{day} \times \frac{1\ day}{8\ hours} \times \frac{1\ hour}{60\ minutes} = 4.25m^3/min$$

Pumps can be categorised into two classes, kinetic and positive displacement. Kinetic pumps increase air flow through centrifugal force using an impeller. They can operate at higher speed which results in smaller pumps capable of high output.

Positive displacement pumps can be broadly grouped into rotary or reciprocating type pumps. In reciprocating pumps, the internal air chamber remains stationary with air flow created through the action of a reciprocating piston. Reciprocating pumps are efficient and capable of generating high pressures. Rotary pumps operate in a similar manner through rotation of lobes or gears to generate flow. Typically, both reciprocating and rotary lobe pumps are large, have high initial costs and have greater number of moving parts and close tolerances therefore the air needs to be free from contaminants to prevent fouling of the internal components.

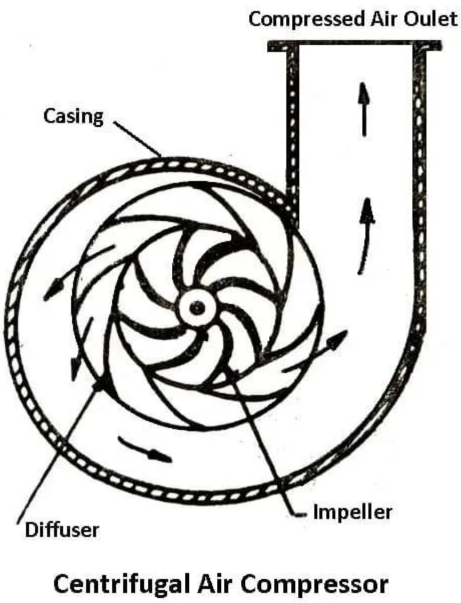


Figure 39: Kinetic pump – Centrifugal air compressor (The Engineers Post 2021)

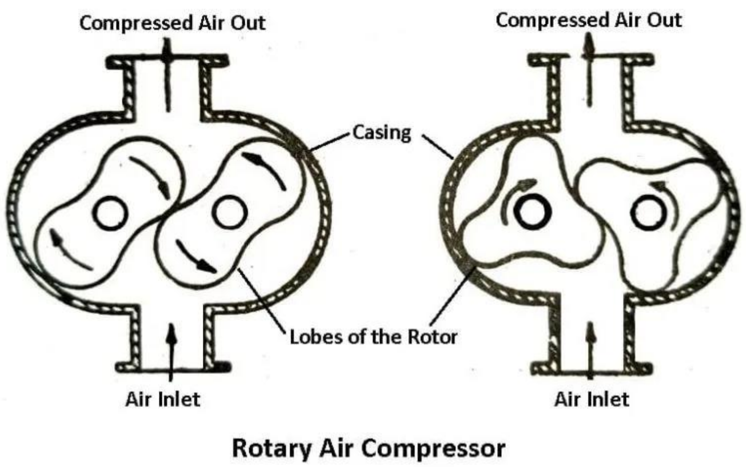


Figure 40: Positive displacement pump – Rotary air compressor (The Engineers Post 2021)

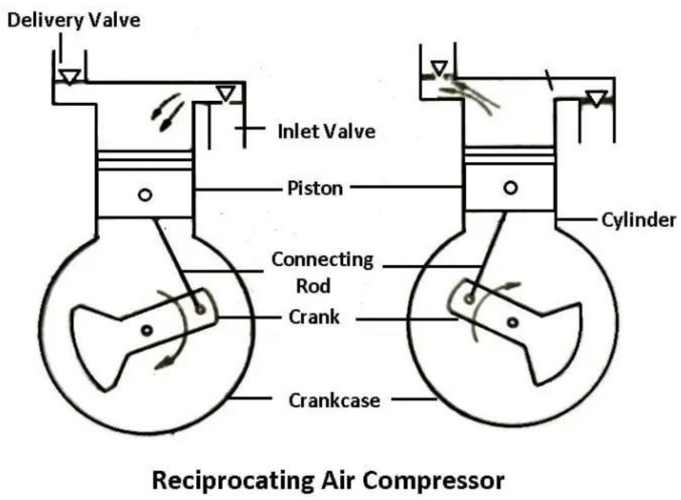


Figure 41: Positive displacement pump – Reciprocating air compressor (The Engineers Post 2021)

Stage 5 Power System

The power system must be sufficient to operate all ancillary subsystems including the blower and control and monitoring systems. The system has three possible options, battery operated, external power or self-generating.

Battery systems offer the benefit of portability however there are possible limitations in the load that can practically be drawn from a system of a modest size. Consideration also needs to be given to lifecycle of batteries, the cost of replacement and the possible challenges of disposing of them in the correct manner in areas that are isolated from battery recycling facilities.

External power including generator and mains power ensures greater reliability of energy supply and volume. Mains power offers the additional benefits with the transferral of maintenance and general responsibility of supply. The trade-off to these benefits is the cost associated with supply and usage charges from the network operator.

A self-generating power system, a system which uses gas produced as a fuel source for a internal combustion engine, is more sustainable yet increases the overall complexity of the design which will also increase the upfront cost and required maintenance routines.

Ancillary Systems

Support Structure needs to secure and support the entire system and be transportable. Strength is the primary consideration in the design of the support frame. Standard structural steel angles complying to AS/NZS 3679.1 - 300MPa will be used for frame construction and AS/NZS 3678 for all structural plate.

The vibrating motor is likely to have a negative effect on sensitive equipment and without isolation from the effects of the motor, it is anticipated that maintenance requirements would greatly increase in frequency and cost. Equipment vulnerable to vibration should be mounted on resilient mounts or part of the support structure should be separated through antivibration mounts.

4.3.7 Concept Analysis

The analysis stage is an iterative process to test the technical feasibility of the design model to identify and rectify where necessary any issues with the proposed design options.

Model Prototype - A key component of the analysis stage is ensuring the model accurately reflects the real-world environment while simultaneously minimising computational effort. To address this, the model geometry will strive to be symmetrical along two planes permitting accurate analysis of a smaller volume of the system. Reducing the volume of analysis permits a finer mesh size and faster, more accurate results. Initially, the system material will be specified using readily available commercial materials based on best judgement, this is likely to change after further investigation.

Once the concept has been modelled in Autodesk Inventor, the model will be packaged for analysis using ANSYS 2021 R1. To simplify the analysis of the prototype, the model will be defeatured where possible to remove any inconsequential features to ensure a clean geometry to begin meshing.

Initial meshing will be automatically generated with tetrahedron elements and upon inspection, functions such as Advanced Size Function and inflation may be used to acquire a practical mesh ready for input of the boundary conditions.

Analysis Input Conditions - To improve the accuracy of the analysis results, laboratory testing will be conducted at the University of Southern Queensland on macadamia nut shells as they undergo gasification in a kiln. While this will differ slightly from the hybrid process this project will follow, it will provide reasonable data for the purpose of creating initial boundary conditions. The benefit of using experimental data will enable a benchmark for comparison against the project that will assist in further refinement of the model mesh and improved accuracy.

Technical Feasibility - ANSYS is a powerful tool that will be used in the analysis of structural, thermal and fluid dynamics (CFD) it will assess the behaviour of the system under varying operating conditions. Structural analysis will calculate the effects of static and dynamic loads to the system and its components to ensure the design is capable of withstanding any loads and avoid premature failure of the system or its components. Thermal analysis will assist in understanding thermal loads on the system to determine temperatures, heat flow rates, and the heat fluxes in a part. Fluid mechanics is important in this project to numerically and visually understand the flow of gases through the design.

It will enable the identification of potentially inconsistent thermal regions that would otherwise negatively impact the rate of thermal decomposition for the feedstock. Together, these tools will ensure that the system and the configuration of its sub-assemblies are suitable for the environment and processes for which it is likely to encounter while minimising risk of failure. Once these behaviours are understood, design improvements can be identified and implemented.

Chapter 5 Detailed Design

The detailed design phase will detail and justify all elements of the final design including drawings, specification and materials list sufficient to permit the construction of a pyrolysis machine.

5.1.1 Design Analysis Phase

The design analysis will be conducted to validate the final design addressing the following key areas of focus, technical, regulatory, financial and socio-economic feasibility.

The technical feasibility analysis will compile, and present experimental data gathered from the USQ laboratory for use in Computational Fluid Dynamics (CFD) to demonstrate boundary conditions, validate modelling data and justify material selection.

Regulatory compliance is vital in determining the future success of the final design. In the absence of well-established regulation, it also provides an opportunity to shape the future of the regulatory framework in the biochar production field.

After establishing material specifications and quantities the overall design cost, along with any additional labour costs and variations in crop productivity, can be calculated and balanced against the anticipated cost savings for traditional agriculture practices. This will lead to an estimated return-on-investment timeline which will encourage further research and on-farm trials to support innovation, market uptake and project success.

Socio-economic analysis will look at the social benefits for the end-user in transitioning away from traditional farming practices toward a more environmentally responsible approach. It will address the impact of public perception on sustainable practices as well as potential roadblocks that may prevent industry uptake and adaptation.

5.1.2 Design

Stage 1 – Delivery System

Hopper

Construction - The hopper is made from welded stainless steel sheet Grade 316 for its high melting point (1370-1400°C) and corrosion resistance properties. It forms the inner chamber of the reactor. It is relatively simple in design with air nozzles protruding in at 90° in the lower half to accommodate air entering the combustion region. The lid seals the chamber protecting from the ingress of air and the loss of heat. The hopper is bolted in place with the design providing the ability to remove the hopper for maintenance and inspections.

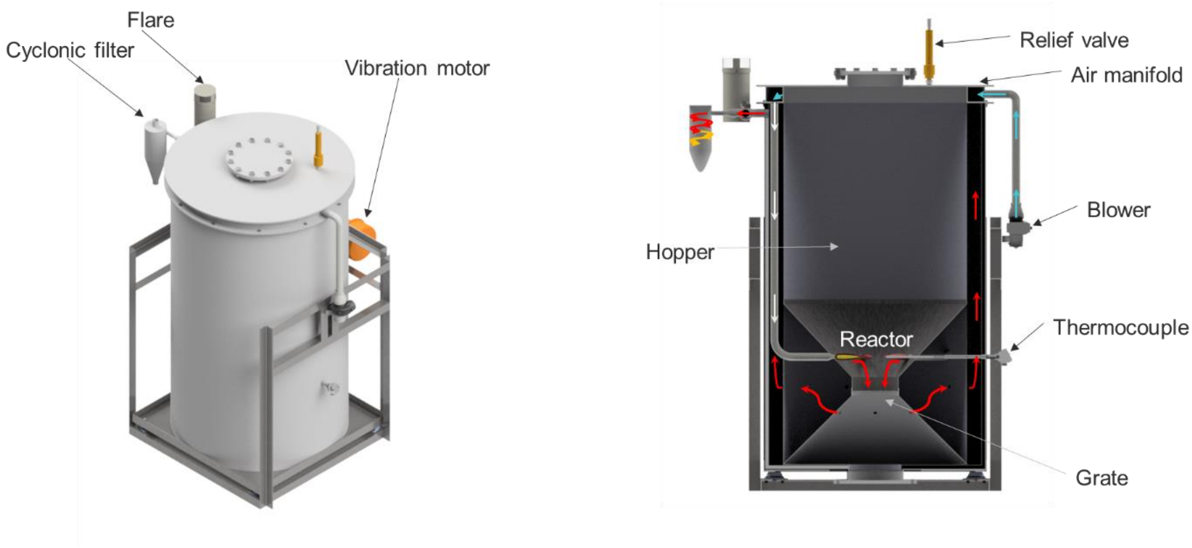


Figure 42: Hopper design

Vibrating Motor

The vibration motor is key in moving biomass through the system stages and if incorrectly sized, it could lead to inefficient operation. The motor needs to be sized to accommodate the system mass including that of the biomass.

Total mass of the feedstock material in the sloped/restricted portion of hopper

- Hopper volume 1000L, Diameter 1150mm
- Imbert nozzle angle 45°
- Nozzle opening 300mm
- Mass of feedstock macadamia nutshell 680kg/m^3

$$Volume = \frac{1}{3} \times \pi R_1^2 \times H_1 - \frac{1}{3} \times \pi R_2^2 \times (H_1 - H_2)$$

$$= \frac{1}{3} \times \pi \times 575mm^2 \times 575mm - \frac{1}{3} \times \pi \times 150mm^2 \times 150mm$$

$$= 199082cm^3 - 3534cm^3 = 195548cm^3 = 195.55L$$

$$Mass = Volume \times Feedstock\ Density = 0.19555m^3 \times 680kg/m^3 = 132.97kg$$

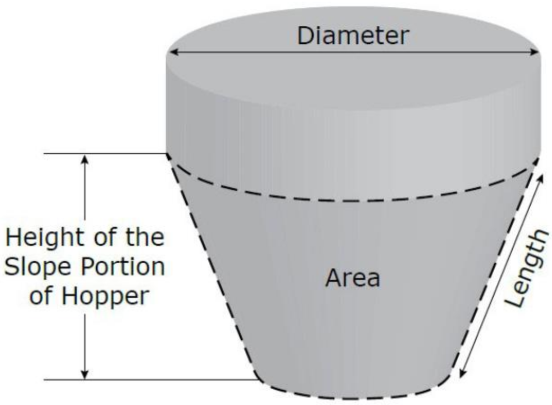


Figure 43: Hopper restriction nozzle

Total mass of the assembled system components including:

- Support frame – 230kg
- Pyrolyser drum assembly – 549kg
- Blowers, vibrator motors, filters and flare – 115kg
- Ducted pipe – 17kg
- 10% miscellaneous contingency

Using the above values gives an indicative combined feedstock and structural mass of approx., 1130kg.

URAS are an internationally recognised supplier of industrial vibration motors and have been identified as an ideal supplier given their reputation in quality. Their motors offer the benefit of being fully enclosed to protect them from dusty environments

Vibration Energy describes the frequency and amplitude of the motor. Finer materials typically benefit from higher frequencies while coarser materials benefit from higher force. Vibration frequency is a function of motor RPM while the vibration force is related to the rotating mass attached to the motor.

Table 6: URAS standard vibration motor specifications

Model		**No. of Poles**	**Vibrating Force (kN)**	**Voltage**	**Speed (rpm)**	**Output (kW)**
Standard	KEE	2	0.5 to 40	200 to 600	3000/3600	0.04 to 3
		4	1.5 to 110		1500/1800	0.065 to 7.5
		6	3 to 185		1000/1200	0.2 to 13
		8	5 to 170		750/900	0.4 to 11

Considering vibration frequency and force are driving design factors, the data in Table 6 indicates that higher vibration can be achieved with fewer poles however vibration force generally increases with the number of poles. Three candidate solutions have been selected in Table 7 to calculate their performance using the following equations:

$$Vibration\ acceleration = \frac{F}{W} = \alpha\omega^2\ m/sec^2$$

$$Vibration\ Strength\ G = \frac{Vibration\ acceleration}{gravity\ acceleration} = \frac{F}{W \times g}$$

$$Angular\ speed\ \omega = 2\pi f$$

$$Vibration\ frequency\ f = \frac{N\ rpm}{60\ sec}$$

$$Vibration\ Amplitude\ \alpha = F/W \times \omega^2$$

Table 7: URAS motor theoretical performance data

Performance	**Model**		
	KEE-110-4WS	**KEE-84-4BWS**	**KEE-75-4BWS**
Vibrating Force (kN)	110	84	75
Speed (rpm)	1800	1800	1800
Vibration Acceleration (m/s^2)	97.1	74.1	66.2
Vibration Strength G	9.9	7.56	6.75
Angular Speed (rad/s)	188.5	1.88.5	188.5
Vibration Frequency (Hz)	30	30	30
Vibration Amplitude (mm)	2.7	2.1	1.9
Cost (AUD)	$12,034	$8,608	$7,134

A general rule of thumb is to apply 1:5 force to weight ratio (vibration strength) for bulky feedstock or 1:10 for lighter materials ($<1.5t/m^3$). To cater for a mid-range feedstock, the KEE-84-4BWS with a vibration strength ratio of 1:7.56 would be sufficient however smaller options can be incorporated to suit different feedstocks.

Stage 2 – Reactor Assembly

The reactor assembly is housed in the lower section of the hopper and is comprised of the inlet nozzle, mesh cup, reduction chamber and air inlet nozzles. Feedstock combustion is propagated with the introduction of air via the air inlets. At completion of the carbonisation process, the brittle char is compressed and agitated against the mesh forcing down into the reduction chamber to cool.

Nozzle – the nozzle is made from welded stainless steel Grade 310 for its superior resistance to corrosion and oxidisation in high temperatures (850°C - 1100°C). The nozzle is comprised of three sections, the inlet, mesh cup and the reduction chamber. The inlet nozzle is angled at 45° to assist in the flowability of feedstock into the combustion region. The aperture of the mesh needs to be small enough to prevent the feedstock from freely passing while also being large enough to permit the permeability of char without excessive input from the vibration motor.

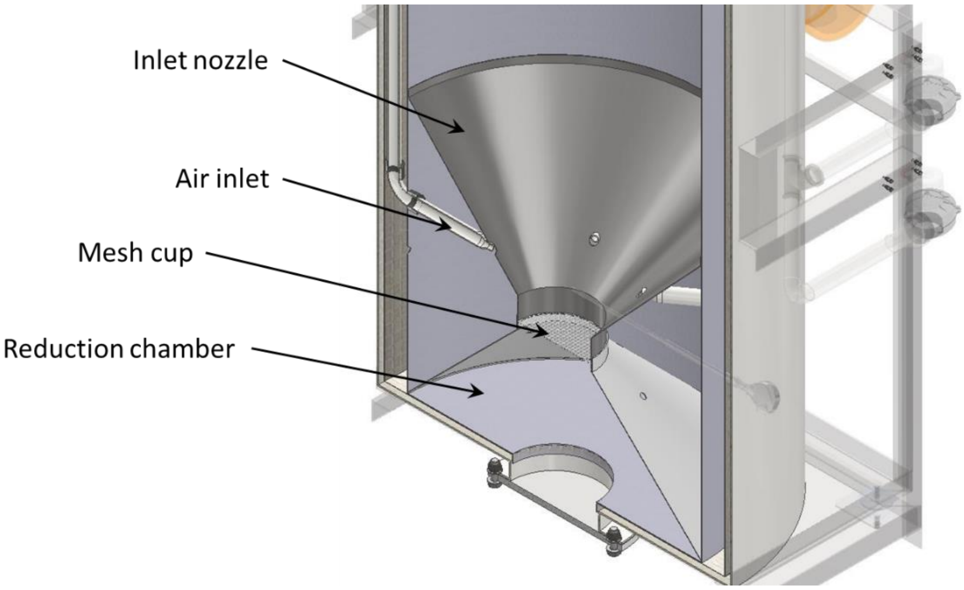


Figure 44: Reactor arrangement

Air inlet lines – five equally spaced air inlet nozzles provide air from the air manifold to the combustion section. An odd number of nozzles is required to prevent supplied air from one nozzle interfering with its opposing nozzle resulting in uneven supply of air and subsequently combustion.

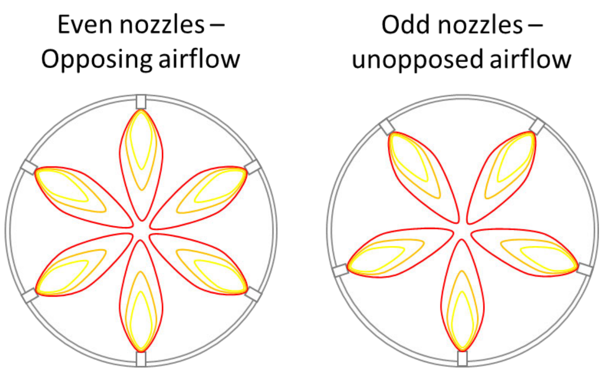


Figure 45: Nozzle combustion arrangement

Stage 3 – Hot Gases

Filter

The filter system will employ a Stairmand high efficiency cyclonic filter to remove gas particles such as ash and carbon. It is ideal for filtration given it is simple in construction, has no moving parts and requires minimal maintenance. Additionally, there is sufficient research to support that there is effective removal of 98% of particles larger than 1.6μm which will greatly assist in meeting the pollution requirements set by NEPM however this should be confirmed in practice at a later date. The remaining composition of gas consists of carbon monoxide and hydrogen which can be harnessed for later combustion.

The effectiveness of the design can be simplified using the Stairmand parameters and can be approximated as follows:

$$N_e = \frac{1}{0.5D}\left(2D\,\frac{2D}{2}\right)$$

Where:

$N_e = \ number\ of\ effective\ turns = 340$

$D = diameter\ of\ cyclone\ body$ = 85mm

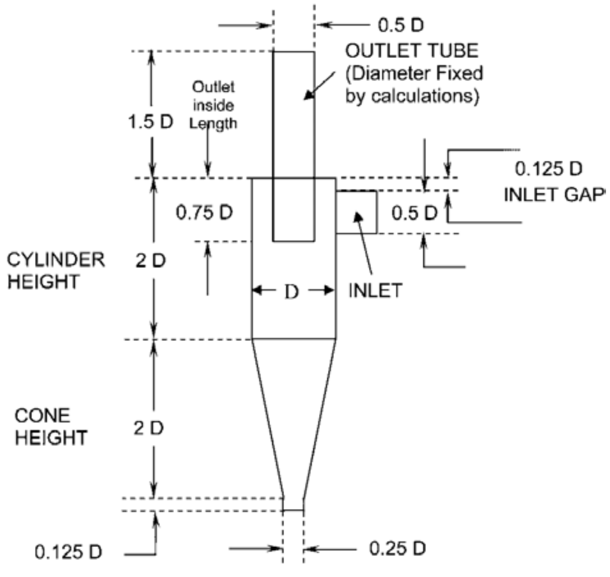


Figure 46: Stairmand cyclone filter dimensions (Moore & McFarland 1993, p. 1844)

Table 8: Air supply data

Blowers in use	Air volume produced	Filter inlet area	Inlet velocity
1	0.05 m^3/sec	0.0014186m^2	35.24 m/sec
2	0.1 m^3/sec		70.49 m/sec

To validate the effectiveness of the filter in capturing particles, The process will be simulated using ANSYS Fluent for a particle size of 2.5μm.

Assuming both blowers are in operation, the filter inlet velocity is 70.49 m/sec

Table 9: ANSYS FEA setup cyclone filter

Simulation Setup	
Conditions	
Inlet velocity	70.49m/sec
Inlet temperature	100°C
Filter body diameter	85mm
Model	
Mesh size	5mm
Nodes	59979
Elements	304696
Element Type	tetrahedron

Setup

Double precision has been selected for greater precision for the current computer specification without compromising speed or performance.

Since the gases are anticipated to be at an elevated temperature, the energy equation has been activated as the thermal properties of the gas may influence its flow characteristics.

The viscosity is set to k-epsilon as the flow of gas is not expected to be laminar. To improve the accuracy of the model, the RNG setting is set to “Swirl Dominated Flow” to emulate the dominant swirl motion in the filter chamber.

Simulating solid ash particles in the gas flow requires the selection and introduction of a “Discrete Phase” which will interact with the gas stream beginning at the cyclone filter inlet. The default material “ash-solid” is selected in the absence of experimental data with a particle size of 2.5μm and 10μm and a velocity to match the full volumetric capacity of both blowers.

Gases produced from the reactor are expected to undergo partial cooling before entering the filter. It is not desirable for the gases to cool below 100°C due to the risk of condensation. Therefore, the filter inlet gas modelled using air properties, will be initially set at 100°C until more accurate data can be obtained

Table 10: Properties of air at 100°C

Density	**Specific Heat**	**Thermal Conductivity**	**Viscosity**
0.9458 kg/m^3	1009 J/kg.K	0.03095 W/m.K	2.181 x 10^{-5} kg/m.s

In the solution methods, the pressure-velocity coupling scheme is set to SIMPLE to speed up the calculation while the Turbulent kinetic energy and dissipation rate are set to second order upwind to improve the accuracy of results.

The results are graphically represented in Figure 47 and indicate that while a portion of the particles exit the cyclone filter through the upper section, the majority rapidly fall and are collected in the lower conical chamber. Given the high velocity of gas entering the cyclone filter inlet, there are concerns that that this could create turbulence that prevents the settling of particles. There are several solutions to such a scenario including increasing the cyclone dimensions to achieve higher effective turns and a larger inlet diameter which would also reduce the inlet velocity slightly. Alternatively, a second cyclone filter can be installed either in parallel to reduce air volume (inlet velocity) or in series to filter out a portion of the remaining particles entrained in the gas.

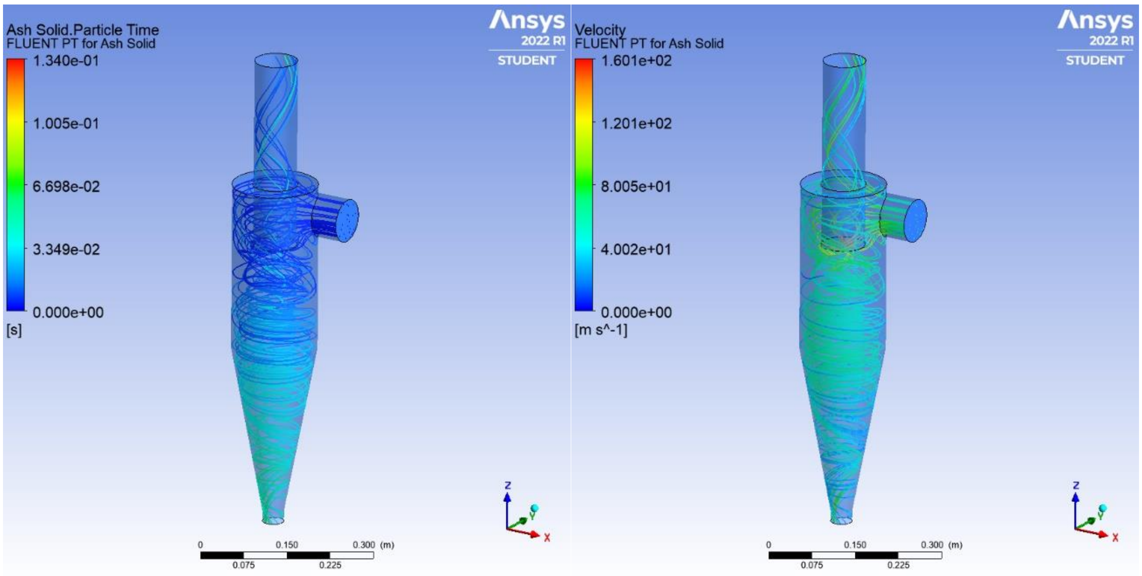


Figure 47: 2.5μm ash particle flow characteristics

Flare

The flare is a rudimentary in design for use during system start-up. It consists of a cylindrical body where the incoming gas mixes with air drawn in from an opening at the bottom. The gas /air mixture is manually ignited through a small ignition port. This process combusts the carbon monoxide and hydrogen produced from the reactor during startup. A mesh screen is fitted at the outlet to prevent the dispersion of embers and the risk of bushfires. Its use is relatively brief, and as such it is not subject to the same thermal environments as the reactor and can be constructed from mild steel to make it more cost effective.

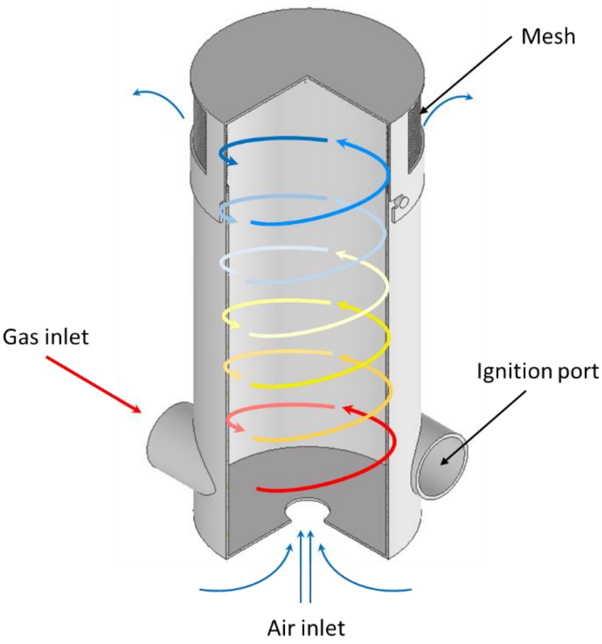


Figure 48: Flare operation

Stage 4 – Monitor & Control Systems

The monitoring and control systems for this project have been simplified to ensure a greater level of effort and detail can be put into the remaining systems. Given that the designer has limited knowledge of electronic and electrical systems, the detailed design for monitoring and control is a recommendation only, serving to provide a general design approach.

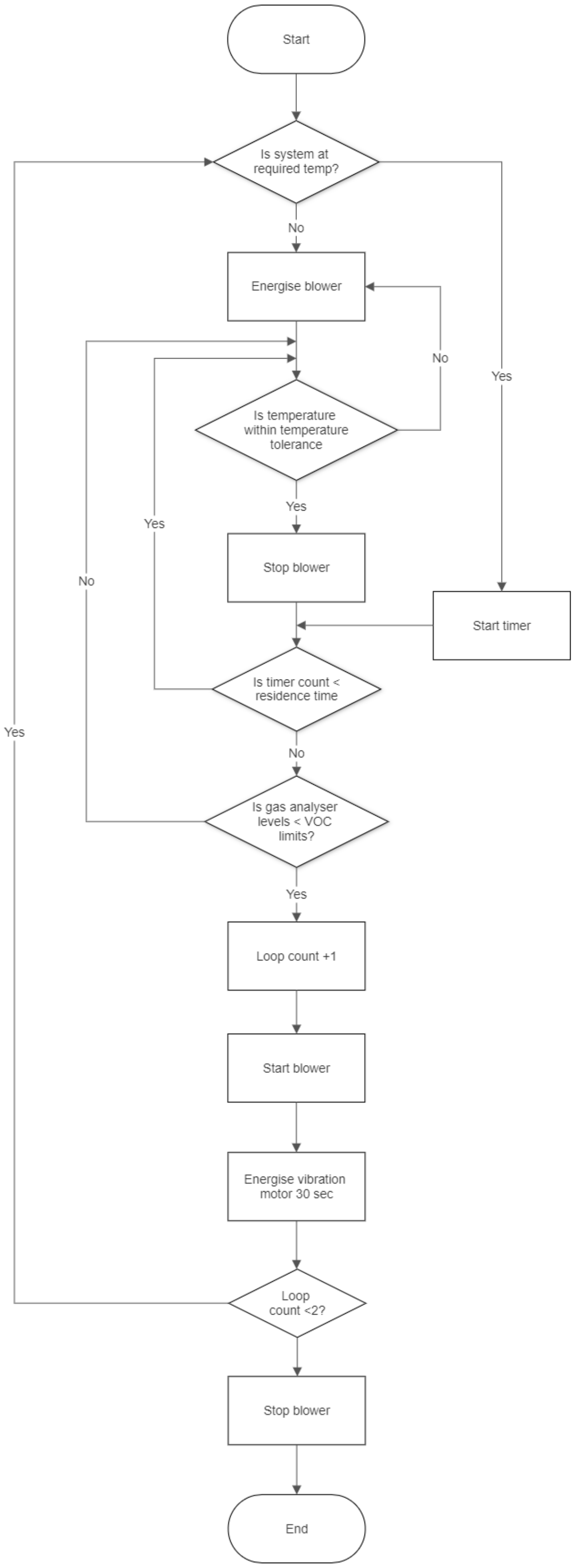


Figure 49: Control and monitoring general operation principle

Monitoring systems

The reactor requires a temperature sensor to provide data input for scheduling the carbonisation process. Therefore, the temperature sensor needs to be constructed with material capable of withstanding the reactors anticipated high temperature of 1000°C.

Type K thermocouples are made from Nickel-Chromium and Nickel-Alumel and are inexpensive, accurate, reliable and the most common in use. They are suitable to a wide variety of environments such as water, mild chemical, gases and dry areas. They are suited to temperature ranges between -273°C to 1260°C with the upper operating temperature range based on the conductor size used.

The thermocouple is installed through a threaded boss connection on the outer drum assembly and penetrates into the reactor.

Table 11: Type K thermocouple specification

Model	Type	Probe length (mm)	Range (°C)	IP	Supplier	Cost
178-0952	K	500	-40 - 1100	67	RS Online	$163.47

Gas Analysers are complex systems and considering there is a need to detect more than one gas at a time, the IR gas analyser while relatively expensive, is an ideal choice for this project. Due to the sensitivity of gas analysers, additional hardware is required to provide a sample that is suitable for analysis. These factors increase both the cost and complexity of the system and offer an opportunity for further design development.

The IR-8400D is suitable to analyse hydrocarbons, carbon dioxide, carbon monoxide and oxygen reliably and accurately. Which are all likely to be present during the carbonisation process Its construction is ideal for extreme environments and the IR-8400D also offers the option for self-calibration, removing additional effort from the operator.

Table 12: IR gas analyser specification

<table>
<tr><th>Model</th><th>Description</th><th>Type</th><th>Temperature range (°C)</th><th>Response time</th><th>Power</th><th>Mass (kg)</th><th>Supplier</th><th>Cost</th></tr>
<tr><td>IR-8400D</td><td>Gas analyser</td><td>NDIR</td><td rowspan="2">-40 to 60</td><td rowspan="2">< 10 sec</td><td rowspan="2">110V 50/60 Hz</td><td rowspan="2">11.3</td><td>Infrared Industries</td><td>$13, 314</td></tr>
<tr><td>IR-1153</td><td>Sample conditioning system</td><td>N/A</td><td>Infrared Industries</td><td>$6,030</td></tr>
</table>

Control systems

Blower

The blower selected is a centrifugal fully enclosed design which was chosen for its relatively low output volume and its ability to operate in a range of environments due to its enclosed construction. Two blowers are required to meet the 4.25m^3/min production requirements identified in Chapter 3.

Table 13: Blower specifications

Blower Specification			
Airflow @ static pressure	2.97m^3/min	**Voltage**	12VDC
Inlet size	Ø 76.2mm	**Current**	4.3A
Outlet Size	Ø 76.2mm	**Noise**	85dB
Speed	1000rpm	**Operating temperature (max)**	54°C

Table 14: Air supply capacity

Blowers in use	**Air volume produced**	**Blower outlet area**	**Outlet velocity**
1	0.05 m^3/sec	0.00456m^2	10.88 m/sec
2	0.1 m^3/sec		10.88 m/sec

To validate the airflow characteristics in the pipework and the air manifold, the process will be simulated using ANSYS Fluent.

Table 15:ANSYS FEA setup – Air supply

Simulation Setup	
Conditions	
Outlet velocity/blower	10.88m/sec
Air temperature	20°C
Pipe diameter	41.91mm
Model	
Mesh	
Mesh type – body sizing	5mm
Mesh type – face sizing	2.5mm
Nodes	47116
Elements	234487
Element Type	tetrahedron

Setup

Double precision has been selected for greater precision for the current computer specification without compromising speed or performance.

In this section of pipework, temperature is not elevated beyond 20°C ambient, therefore the energy equation is not required.

The viscosity is set to k-epsilon as the flow of gas is not expected to be laminar. The remaining parameters have been left as per default settings.

Table 16: Properties of air at 20°C

Density	Specific Heat	Thermal Conductivity	Viscosity
1.204 kg/m^3	1007 J/kg.K	0.02514 W/m.K	1.825 x 10^{-5} kg/m.s

Results

One of the biggest concerns with the current arrangement is the capacity for the selected blowers to overcome the backpressure exerted by the pipework fittings and the feedstock. The pipework depicted in Figure 50 indicates the backpressure is more than 7kPa which, in combination with other downstream flow restrictions, may prove too great for the 12V blowers.

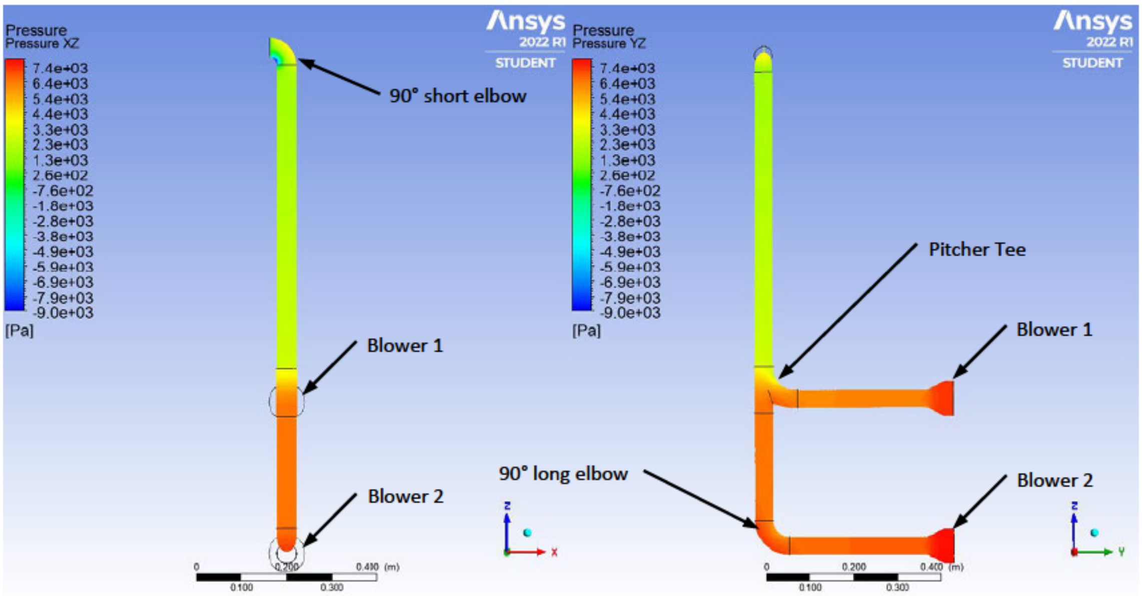


Figure 50: Air manifold inlet pressure characteristics

As anticipated, the areas of increased pressure in Figure 50 are accompanied with relatively low air velocity in Figure 51. The velocity profile on the inside radius of the 90° short elbow is approx. 130m/s while 85m/s on the outer radius. This variation in air velocity is likely to induce the turbulence in this area and increase the backpressure on the blowers. This issue could be alleviated with the replacing of the current 90° short elbow with a 90° long elbow.

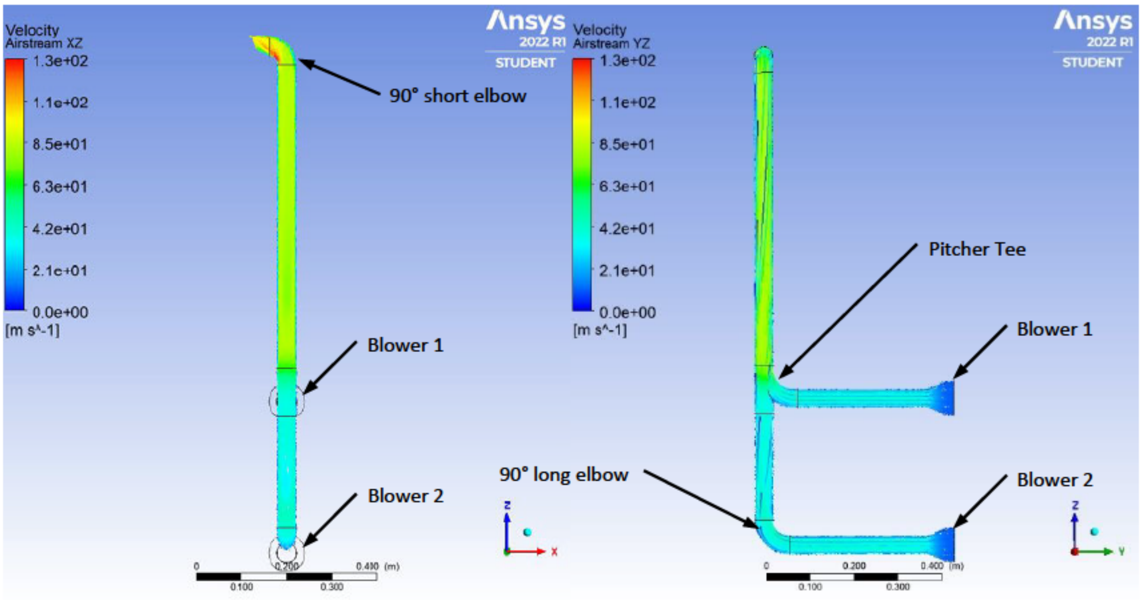


Figure 51: Air manifold inlet velocity characteristics

Simulation Setup	
Conditions	
Manifold inlet Velocity	88m/sec
Air temperature	20°C
Pipe diameter	35.05mm
Nozzle diameter	15.8mm
Model	
Mesh	
Mesh type	Default
Nodes	91056
Elements	409018
Element Type	tetrahedron

Setup

Double precision has been selected for greater precision for the current computer specification without compromising speed or performance.

In this section of pipework, temperature is not elevated beyond 20°C ambient, therefore the energy equation is not required.

Considering the pipe fittings, sharp bends and general geometry inside the manifold, the viscosity is set to k-epsilon as the flow of gas is not expected to be laminar. The remaining parameters have been left as per default settings as precision results are not required at this stage of analysis.

Results

Air is entering the manifold at approximately 85m/s and directed directly at the manifold inner wall. This impact creates a lot of turbulence as shown in the velocity streamlines depicted in Figure 52. Turbulent air is not desirable when trying to maintain a controlled release of air to the combustion chamber. Opposite the manifold inlet there is a segment of the manifold that receives very little airflow, this may lead to a thermal hotspot in that region however given the airflow rates in the other sections, any heat in this region is expected to dissipate relatively quickly.

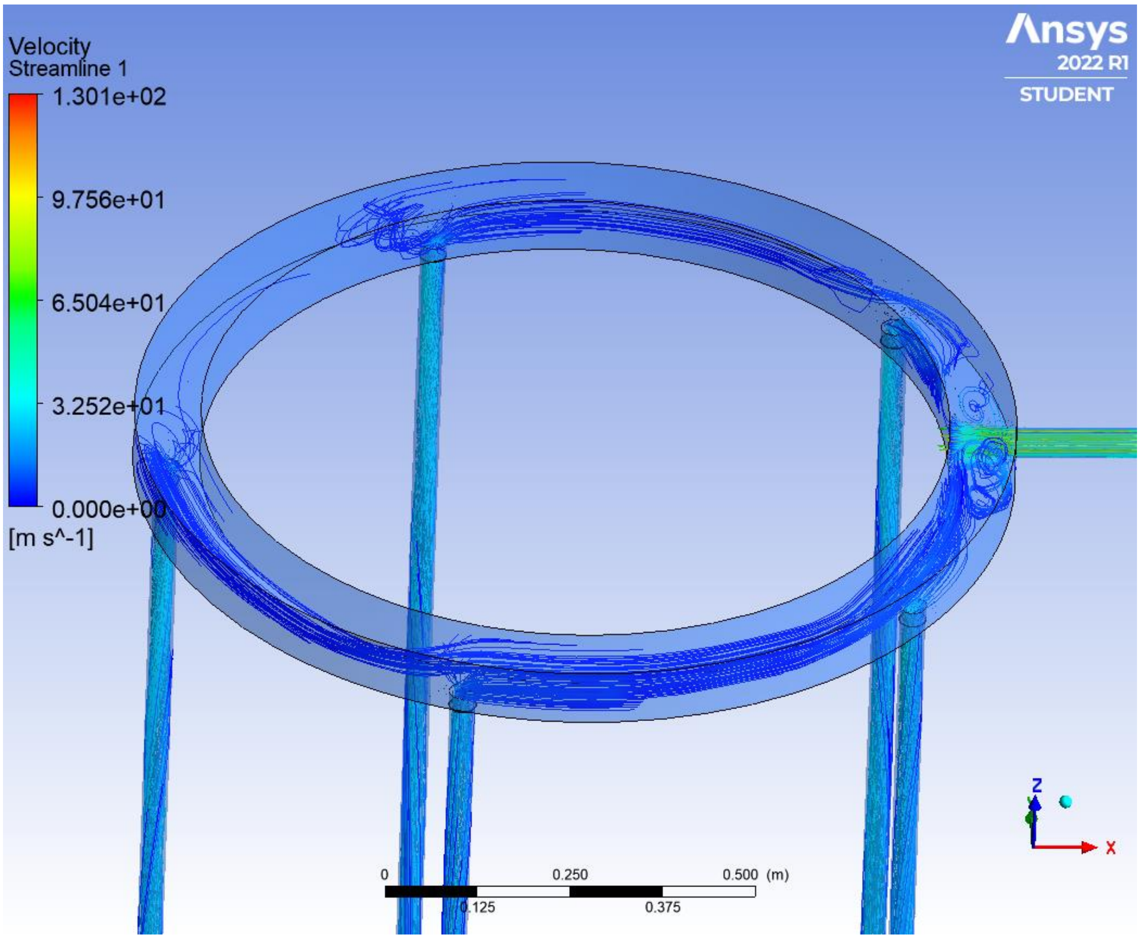


Figure 52 Manifold velocity streamline

There are issues displaying the results across each downpipe where the cross section created from the ZX plane has duplicated along each downpipe (72° rotation) as shown in Figure 53. This issue places doubt on the results presented for four of the down pipes. The pipe opposite the inlet is believed to be a true representation for that location and is shown. The air velocity indicates a velocity of around 126m/s which is concerning at such a large volume (24.7L/s) that complete combustion of the feedstock in the line of the air stream will occur before the peripheral regions carbonise.

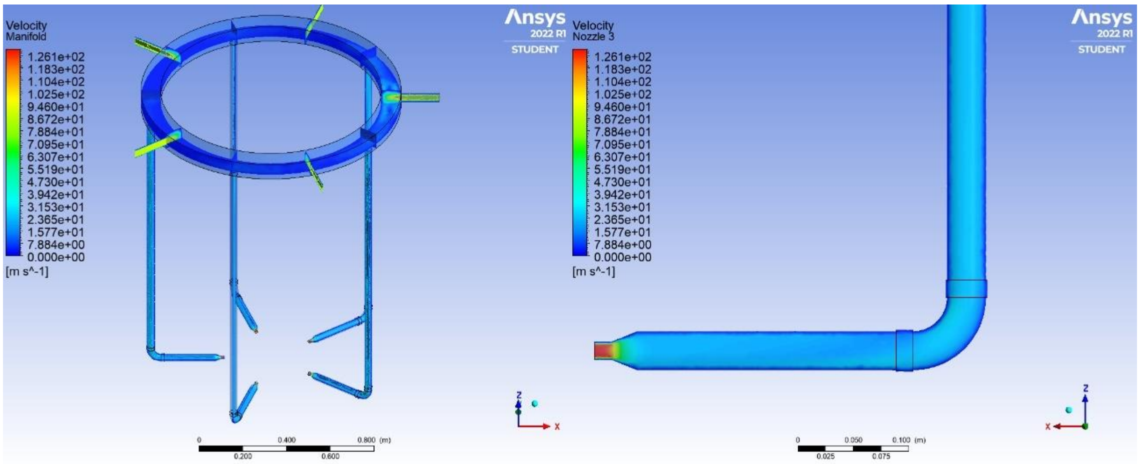


Figure 53: Manifold velocity profile

Support Structure

The support structure is constructed using generic mild streel angle section, with two separate structures connected through four anti vibration mounts. The design prevents the transmission of vibrations from the vibration motor to other system components.

The horizontally mounted vibration motor generates vibrations in the vertical and horizontal axis therefore the anti-vibration mount needs to be capable of dampening motion in all three axes.

The vibration mounts were selected using the following inputs against Figure 54:

Table 17: Vibration mount selection data

Parameter	**Total mass (kg)**	**Number of mounts**	**Motor speed (rpm)**
Value	1250	4	1800

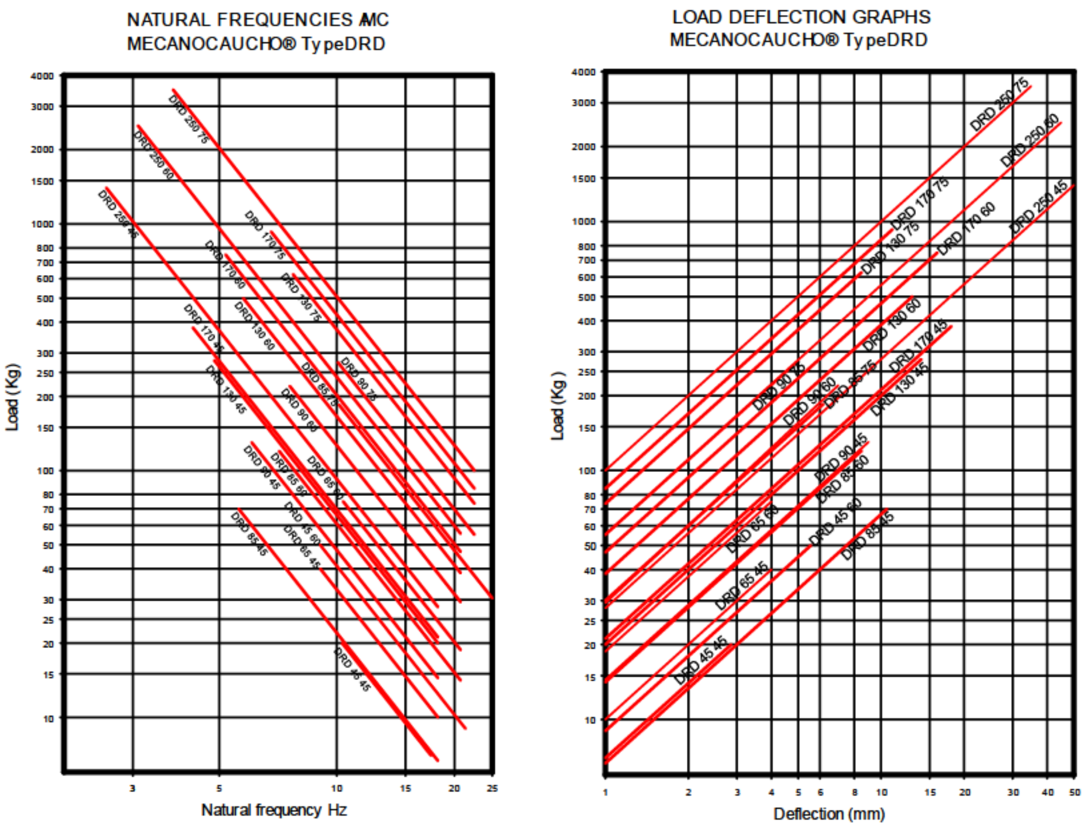


Figure 54: DRD type vibration mount performance data

Beginning with the load/deflection diagram in Figure 54, we can identify possible solutions assuming the 1250kg is evenly distributed across 4 mounts, the rated deflection and frequency for each option can be determined:

Table 18: Vibration mount characteristics

Mount Options Characteristics								
Model	**DRD 250 75**	**DRD 170 75**	**DRD 130 75**	**DRD 250 60**	**DRD 170 60**	**DRD 130 60**	**DRD 250 45**	**DRD 170 45**
Deflection (mm)	3.2	3.7	4.25	5.65	6.4	8.1	10.4	15
Natural Frequency (Hz)	12.9	12	11	9	8.4	7.75	5.6	4.7
Stiffness Coefficient (k)	9.6E+05	8.3E+05	7.2E+05	5.4E+05	4.8E+05	3.8E+05	2.9E+05	2.0E+05
Forcing Frequency (f_d) Hz	30	30	30	30	30	30	30	30
Natural Frequency (f_n) Hz	13.84	12.87	12.01	10.42	9.79	8.70	7.68	6.39
Transmission (T)	0.27	0.23	0.19	0.14	0.12	0.09	0.07	0.05
Isolation %	**73**	**77**	**81**	**86**	**88**	**91**	**93**	**95**

$$k = \frac{Force}{Deflection}$$

$$Forcing\ frequency\ f_d = \frac{1800rpm}{60\ sec/min} = 30Hz$$

$$Natural\ Frequency\ f_n = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Transmission of vibrations from the motor to the support structure:

$$T = \frac{1}{(\frac{f_d}{f_n})^2 - 1}$$

The information presented in Table 18 is useful in identifying the level of isolation provided by the vibration mount for a given mass. As there are no items identified that are specifically sensitive to vibrations a conservative selection has been chosen for this project, the DRD 130 60 which offers 91% isolation from the motor vibrations.

Design Cost

The cost of the system has been assumed in many instances and is intended as a guide only. The values below will change with market price and some items may be considerably cheaper if multiple suppliers were identified.

Item	Quantity	Supplier	Part Number	Unit Cost	Total Cost
Blower	2	McMaster-Carr	2059K12	\$109.04	\$218.08
Vibration Motor	1	URAS	KEE-84-4BWS	\$8,608	\$8,608
Anti-vibration mounts	4	DRD 130 60	135318	\$207.79	831.16
Thermocouple – Type K	1	RS Online	178-0952	\$163.47	\$163.47
Gas Analyser	1	Infrared Industries	IR-8400D	\$13,314	\$13,314
Gas Conditioner	1		IR-1153	\$6,030	\$6,030
L Shaped Angle	7.735m	Handy Steel	65x65x6	\$25.76/m	\$199.25
Steel Plate	1	Handy Steel	1200x1200x6	\$286.39	\$286.39
Steel plate	1	Handy Steel	1300x1300x10	\$462.12	\$462.12
Steel plate	2	Handy Steel	1200x1200x5	\$236.49	\$472.98
SS threaded half coupling 1 1/4	15	ANZOR			\$213.3
Steel Pipe	1.9m		1 ½ Sch. 40	TBC	TBC
Stainless Steel Sheet			1200x1200x2	TBC	TBC
Stainless steel pipe	1.6m		1 ¼ Sch. 40	TBC	TBC
Fittings				Est.	\$300
Attaching hardware				Est	\$250
Total*					**\$31,348.75**
*Total does not include cost of pipe					

Chapter 6 Conclusion

6.1 Introduction

The purpose of this research project was to design a small scale pyrolyser for the production and use of char in the agricultural industry. The objective of this research was to identify the need and causes for the design of a pyrolyser and to identify design requirements to ensure the final design was compliant with industry and regulatory requirements. The design objective was aimed at using the requirements identified and engineering knowledge to produce a concept design that could be validated against available data.

6.2 Discussion

The findings from this research project are that the production of char for use in the agriculture industry shows great promise. The aim of this project has been largely achieved with the conceptual design of a small scale pyrolyser that can be deployed for use in the agriculture sector. The concept can be tailored to suit a range of feedstocks with potential for a tailored char to suit a desired application.

There is currently however, limited or inconsistent data in relation to the use of char in soil conditioning and this poses a concern that the addition of char to soil may be less effective or even detrimental when compared to current waste management methods such as mulching and slash and burn practices. While existing research for the broad application of char to soil has shown mixed results, it’s apparent that irregularities in the presented data, variations in char production methods and target soils, has somewhat complicated the results.

During the literature review, the need to evolve current practices in agriculture to meet the needs of future generations in a challenging climate was ever clear. Despite this obvious need and given society’s propensity to alter their surroundings with little consideration beyond their own needs, an ethical dilemma exists. Given the current limited regulation in char production, can the general public be trusted to use char appropriately given its potential risk to Australian soils, which while inherently degraded, form part of their own unique biodiverse environments. There may be an undesired impact to the existing environment that may lead to an imbalance or the introduction of a species that competes or preys upon inhabitants of the natural ecosystem.

The literature review provided a sound starting point to understand the requirements of char production and the various systems to support it, which became more complex and involved than initially anticipated. This complexity was particularly challenging when seeking practical and cost-effective ways to manage gas emissions. This led to considerable rework of the baseline design rather late in the project at the cost of the development of ancillary systems.

Initially the intent was to leverage data gathered from the gasifier on UniSQ's Toowoomba campus for use in modelling and validation however, following a long period without use during the COVID pandemic, the system failed to provide usable data following several attempts. This required a different approach which had a greater focus on engineering theory to validate elements of the design.

The design presented in this project is capable of producing char for multiple agriculture industries, however given the high initial costs associated with this design, further analysis needs to be conducted to refine the design prior to constructing a prototype.

Full validation of this design was an extremely ambitious goal areas such as structural analysis, emissions analysis and the heat transfer analysis all could have had been their own project scope.

6.3 Further Research and Recommendations

Research

Current research data on feedstock properties, carbonisation process and soil application details are inconsistent and difficult to compare given the slight variations in the variables and methodologies. In order to determine the best feedstock, carbonisation process and char application is achieved for a desired outcome, further field testing and research is necessary.

Design

For a full and comprehensive design, this project still requires the input of electrical SME's to identify any gaps in the current design and complete the design for the monitoring and control systems with particular attention required on the gas analysis and programming of the control system.

Automation is critical in the success and adoption of a pyrolyser system, and it is identified and recommended that an automated feed mechanism be added to convert the current batch style system in into a continuous operation. Additional inclusions for automation include sensors in the hopper and possibly the reduction chambers to prevent exceeding the storage capacity of each.

Structural assessment of the support frame is required which may assist in reducing the sizes of the structural steel angels required and subsequently the overall cost. Likewise structural and thermal analysis is required on the Inner drum, Outer Drum and Lid to identify areas for cost and weight saving.

Initially this project arbitrarily identified the processing of two full batches in an eight hour period to increase productivity. This increase in production required shorter residence times and greater rate of air supplied to the reactor. Currently the baseline design includes five air supply nozzles of a fixed diameter resulting in air flow in excess of 126m/s. There are concerns that at this velocity the feedstock will undergo complete combustion at the air inlet nozzles while volatiles present in the gases will not have adequate time to burn off. It is recommended that one, or a combination of the following occur:

- The number of air inlets be increased to seven
- The air inlet nozzle diameter be increased to reduce air velocity
- The production capacity be reduced to a single batch in an eight hour period

Industry

Not all chars are created equal and as such the commercialisation of char has limitations as there are inconsistent quality chars being sold as the same product. This requires the development of better regulations of the char production industry and standards need to be developed to ensure a better way to grade the quality of chars produced.

6.4 Summary

Population growth and the impacts of climate change will place food and water security under intense strain. Agricultural production will need to adapt in order to achieve the required output to meet the needs of the future.

Char production as a sustainable means of waste management and soil remediation could be part of that solution.

The design presented in this project is suitable for many agriculture industries and is capable of char production at relatively large scale. However, there are still many areas of the design, particularly the electrical and control and monitoring systems that require attention. Additionally given the high initial cost associated with the manufacture of this design, further work is required to validate and improve upon the existing model.

Appendix A Project Specification

ENG4111/4112 Research Project

Project Specification

For: Gregory Michael Allen

Title: Design of a Small-Scale Pyrolysis Machine

Major: Mechanical Engineering

Supervisors: Dr Les Bowtell, Senior Lecturer USQ

Dr Kahlid Saleh, Lecturer USQ

Enrolment: ENG4111 – EXT S1, 2022

ENG4112 – EXT S2, 2022

Project Aim: The aim of this project is to design a portable pyrolysis machine for the sustainable production of biochar in the agriculture industry.

Programme: Version 1, 28th February 2022

1. Conduct initial background research on challenges faced in the Australian agriculture industry with a focus on waste management, climate change and sustainable practices.
2. Identify different agriculture waste and its suitability as a feedstock in the pyrolysis process.
3. Review the effects of pyrolysis processes on various agriculture feedstock.
4. Research methods for pyrolysis and processes, identifying systems and subsystems required to facilitate the feedstock drying, combustion, exhaust process and the control systems required to maintain a safe and proper system function.
5. Select a suitable method of pyrolysis for given feedstock and environment.
6. Design a small-scale pyrolysis machine for use in the agriculture industry.
7. Validate pyrolizer design using CAD software and identify areas for improved efficiency.

If time and resource permit:

8. Conceptualise, design and incorporate a pre-treatment (drying) stage to the primary design.

9. Conceptualise, design and incorporate a volatile gas extraction system to improve system efficiency and sustainability of the primary design.

Appendix B Risk Assessment

UNIVERSITY OF SOUTHERN QUEENSLAND

University of Southern Queensland **Offline Version**

USQ Safety Risk Management System

Note: This is the offline version of the Safety Risk Management System (SRMS) Risk Management Plan (RMP) and is only to be used for planning and drafting sessions, and when working in remote areas or on field activities. It must be transferred to the online SRMS at the first opportunity.

Safety Risk Management Plan – Offline Version			
Assessment Title:	ENG4111/4112 - Engineering Research Project 2022	Assessment Date:	14/03/2022
Workplace (Division/Faculty/Section):	204000 - Faculty of Health, Engineering and Sciences	Review Date:(5 Years Max)	Click here to enter a date.
Context			
Description:			
What is the task/event/purchase/project/procedure?	ENG4111/4112 - Engineering Research Project & Dissertation		
Why is it being conducted?	In fulfilment of ENG4111 and ENG4112 Research Project		
Where is it being conducted?	In students home office (Hillsdale NSW) and P7 Engine Room		

Course code (if applicable)	ENG4111 and ENG4112	Chemical name (if applicable)	

What other nominal conditions?	
Personnel involved	Gregory Allen (Student)
Equipment	Personal computer, Gasifier
Environment	Home office/P7 Engine Room
Other	
Briefly explain the procedure/process	The gasifier is filled with feed stock and ignited using a small hand-held propane burner. The combustion process produces a combustible gas which is either sent to the flare or used in the engine to power the generator. The airflow is manipulated to control the operating temperature. When the airflow is closed off, the process stops and the gasifier cools down.
Assessment Team - who is conducting the assessment?	
Assessor(s)	Belal Yousif
Others consulted:	Les Bowtell (Supervisor)

Eg 1. Enter Consequence

Eg 2. Enter Probability

Eg 3. Find Action

	Consequence				
Probability	**Insignificant** No Injury 0-$5K	**Minor** First Aid $5K-$50K	**Moderate** Med Treatment $50K-$100K	**Major** Serious Injuries $100K-$250K	**Catastrophic** Death More than $250K
Almost Certain 1 in 2	M	H	E	E	E
Likely 1 in 100	M	H	H	E	E
Possible 1 in 1000	L	M	H	H	H
Unlikely 1 in 10 000	L	L	M	M	M
Rare 1 in 1 000 000	L	L	L	L	L

Recommended Action Guide
E=Extreme Risk – Task ***MUST NOT*** proceed
H=High Risk – Special Procedures Required (See USQSafe)
M=Moderate Risk – Risk Management Plan/Work Method Statement Required
L=Low Risk – Use Routine Procedures

Gregory Allen [redacted]

ENG4111 - Research Project Part 1: Risk Management Plan

Step 1 (cont.)	Step 2	Step 2a	Step 2b	Step 3			Step 4				
***Hazards*:** From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
Computer hardware/software failure	Loss of project work resulting in increased stress levels	Insignificant	Regular file backup on multiple devices. Financial savings to replace damaged hardware. Anti-virus software.	Unlikely	Low	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Poor workstation ergonomics	Weight gain. Musculoskeletal disorder	Insignificant	Work office has been set-up using Comcare and Safe Work Australia guidance.	Rare	Low	Yes	Take regular breaks and incorporate stretching activities.	Insignificant	Rare	Low	Yes or No
Increased workload	Increased stress and deterioration in mental health	Insignificant	Established routine to improve work life balance. Balanced diet. Prioritised sleep routine.	Likely	Moderate	Yes or No	Incorporate outdoor exercise to routine	Insignificant	Rare	Low	Yes or No
Machinery operating at high temperatures	Burns to personnel	Minor	Use flame resistant PPE including long sleeve shirt and pants, enclosed shoes and thermally insulated gloves.	Possible	Moderate	Yes		Select a consequence	Select a probability	Select a Risk Level	Yes or No
Machinery	Injury to personnel	Minor	Electrically and mechanically	Unlikely	Low	Yes					

Step 1 (cont.)	**Step 2**	**Step 2a**	**Step 2b**	**Step 3**			**Step 4**				
***Hazards*:** From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
moving parts			isolate equipment during setup and shutdown. Remove all loose personal items. Ensure correct workshop PPE standards are adhered to.								
Chemical	Personnel exposed to chemicals	Moderate	Ensure all chemicals are identified and accompanied with a current SDS and a copy is retained in the workshop register for the duration of the task. Personnel will use appropriate PPE as identified in SDS. Chemicals will be stored with reference to SDS and lab guidelines.	Rare	Low	Yes					
Exhaust &	Build up and exposure	Insignificant	Serviceable gas monitor to be	Rare	Low	Yes					

Gregory Allen [redacted]

ENG4111 - Research Project Part 1: Risk Management Plan

Step 1 (cont.)	**Step 2**	**Step 2a**	**Step 2b**	**Step 3**			**Step 4**				
Hazards: From step 1 or more if identified	***The Risk:*** What can happen if exposed to the hazard without existing controls in place?	***Consequence:*** What is the harm that can be caused by the hazard without existing controls in place?	***Existing Controls:*** What are the existing controls that are already in place?	***Risk Assessment:*** Consequence x Probability = Risk Level			***Additional controls:*** Enter additional controls if required to reduce the risk level	***Risk assessment with additional controls:***			
				Probability	**Risk Level**	**ALARP? Yes/no**		**Consequence**	**Probability**	**Risk Level**	**ALARP? Yes/no**
gas emissions	to harmful gases		located adjected to gasifier. Extraction fans to be in use and open all windows. Only personnel required to conduct and monitor the task shall be inside the lab.								
Workshop Environment	Slips, Trips, Falls,	Insignificant	Personnel must complete a building induction prior to conducting activities and be conversant with the location of exits, medical stations, and emergency contact processes. Personnel must adhere to workshop protocols (PPE) when entering lab.	Possible	Low	Yes					

Gregory Allen [redacted]

ENG4111 - Research Project Part 1: Risk Management Plan

Step 5 - Action Plan (for controls not already in place)			
Additional controls:	*Resources:*	*Persons responsible:*	*Proposed implementation date:*
Take regular breaks and incorporate stretching activities.	None	Gregory Allen	14/03/2022
Incorporate outdoor exercise to routine.	None	Gregory Allen	14/03/2022
			Click here to enter a date.

Step 6 - Approval			
Drafter's name:	Gregory Allen	Draft date:	14/03/2022
Drafter's comments:			
Approver's name:	Les Bowtell	Approver's title/position:	
Approver's comments:	I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.		
I am satisfied that the risks are as low as reasonably practicable and that the resources required will be provided.			
Approver's signature:		Approval date:	Click here to enter a date.

Appendix C Project Resources

ENG4111/4112 Research Project

Project Resources

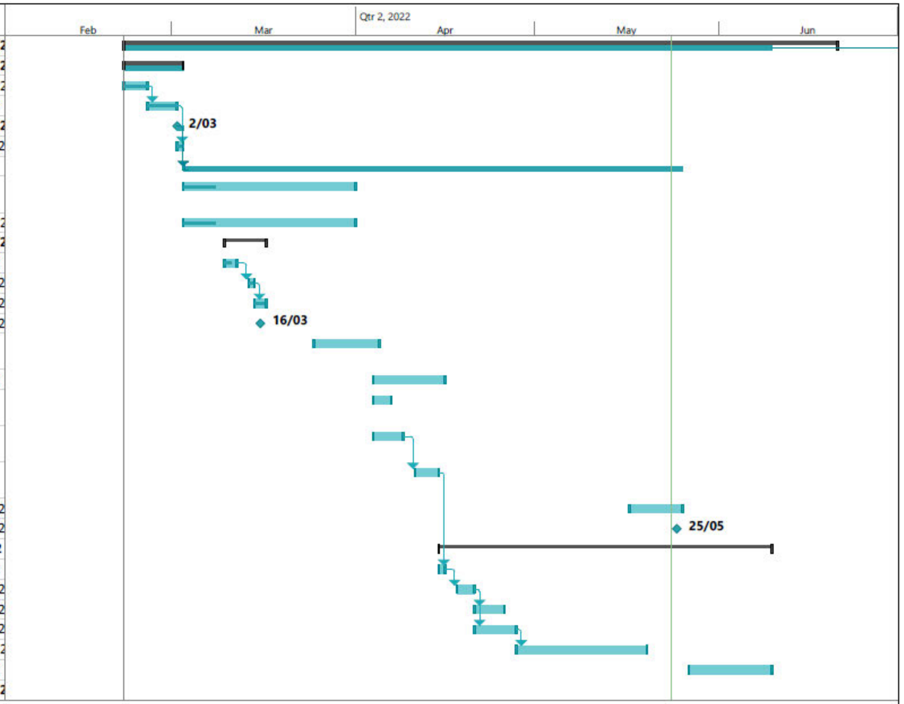
ID	Resource	Resource Type	Purpose
1	Computer/Laptop with the following minimum specifications: - Microsoft Windows 10, 64-bit - 4 GB RAM - 25 GB hard drive space - Computer must have a physical C:/" drive present - Graphics card and driver: Professional workstation class 3-D - OpenGL-capable	Hardware	Required to install and operate CAD software (ANSYS & CREO)
2	3 button mouse	Hardware	Required for efficient CAD modelling
3	External hard drive: - Min 1TB storage space - USB compatible	Hardware	Backup storage for project
4	ANSYS Student 2021 R1	Software	Modelling and analysis of design
5	Creo University Student Edition 8.0	Software	Required for fluid flow analysis
6	MS Office Suite including: - MS Word - MS Excel - MS PowerPoint - MS Project	Software	Compilation of reports/dissertation Basic calculations Presentations Project management
7	Zoom Video Conferencing	Software	Communication
8	Google Documents	Software	Document sharing and review
9	Internet	Technology	Research Communications Access to USQ Studydesk and resources
10	USQ Engineering laboratory	Facilities	Validation of thermal, chemical and physical properties against theoretical and modelled data

Gregory Allen [redacted]

ENG4111 - Research Project Part 1: Project Plan

Appendix D Project Plan

ID	Task Mode	Task Name	Duration	Start	Finish
1		**ENG4111**	**86 days**	**Mon 21/02/2**	**Mon 20/06/2**
2	✓	**Preparartion Phase**	**8 days**	**Mon 21/02/2**	**Wed 2/03/22**
3	✓	Secure Resources	4 days	Mon 21/02/2	Thu 24/02/22
4	✓	Complete Project Proposal	3 days	Fri 25/02/22	Tue 1/03/22
5	✓	**Assignment 1 - Topic Allocation**	**0 days**	**Wed 2/03/22**	**Wed 2/03/22**
6	✓	Submit Project Proposal	1 day	Wed 2/03/22	Wed 2/03/22
7		**Research Phase**		**Thu 3/03/22**	
8		Research and identify Agriculture soil types	21 days	Thu 3/03/22	Thu 31/03/22
9		Identify degraded soil properties	21 days	Thu 3/03/22	Thu 31/03/22
10		**Assignment 2 - Project Specificati**	**5 days**	**Thu 10/03/2**	**Wed 16/03/2**
11		Project Plan	2 days	Thu 10/03/2	Fri 11/03/22
12		Project Resources	1 day	Mon 14/03/2	Mon 14/03/2
13		Project Specification	2 days	Tue 15/03/2	Wed 16/03/2
14		Submit Project Specification	0 days	Wed 16/03/2	Wed 16/03/2
15		Research and identify crop types used in degraded soils	7 days	Fri 25/03/22	Mon 4/04/22
16		Mid Semester break	10 days	Mon 4/04/22	Fri 15/04/22
17		Identify feedstocks readily available in Australian Agriculture	3 days	Mon 4/04/22	Wed 6/04/22
18		Research effects of pyrolysis on various feedstocks	5 days	Mon 4/04/22	Fri 8/04/22
19		Research current pyrolysis machine features	4 days	Mon 11/04/22	Thu 14/04/22
20		Draft Progress Report	7 days	Tue 17/05/2	Wed 25/05/2
21		Assignment 3 - Progress Report	0 days	Wed 25/05/2	Wed 25/05/2
22		**Preliminary Design Phase**	**40 days**	**Fri 15/04/22**	**Thu 9/06/22**
23		Create Systems Diagram	1 day	Fri 15/04/22	Fri 15/04/22
24		Identify system requirements	3 days	Mon 18/04/2	Wed 20/04/2
25		Supervisor Review	3 days	Thu 21/04/2	Mon 25/04/2
26		Concept design development	5 days	Thu 21/04/2	Wed 27/04/2
27		Draft model design	16 days	Thu 28/04/2	Thu 19/05/22
28		Supervisor concept design review	10 days	Fri 27/05/22	Thu 9/06/22
29		**ENG4112**	**86 days**	**Mon 11/07/2**	**Mon 7/11/22**



Project: Biochar.mpp
Date: Tue 24/05/22

Task | Split | Milestone | Summary | Project Summary | Inactive Task | Inactive Milestone | Inactive Summary | Manual Task | Duration-only | Manual Summary Rollup | Manual Summary | Start-only | Finish-only | External Tasks | External Milestone | Deadline | Progress | Manual Progress

Appendix E Design Requirements

ID	Requirement Category	Requirement Type	Source Document	Source Ref	Requirement Detail	Priority
	Functional			Designer	Feedstock must not exceed $25mm^2$ to encourage flowability and homogeneous carbonisation	Mandatory
	Functional			Designer	System shall be designed to accommodate feedstock from various sources	Desirable
	Functional			Designer	The system should be capable of processing 1000 litres of biomass in a single batch.	Desirable
	Functional			Designer	The system should be capable of processing two complete batches in a standard 8hr day.	Desirable
	Safety			Designer	Sufficient mechanical and electrical safety measures shall be incorporated into the design to protect plant operators	Mandatory
	Safety			Designer	Emissions from the pyrolysis process shall be minimised	Mandatory
	Environmental				Feedstock must be sourced from sustainable biomass	Mandatory
				Designer	Biochar properties should be homogenous	Desirable
	Functional			Designer	Biochar production process should be repeatable and provide sufficient adjustment to temperature and holding times to account for various feedstock and desired properties	Desirable
	Environmental			Designer	Biochar must not have any adverse impacts to the environment, soil or livestock	Mandatory

	Functional	Industry Body	ANZBIG CoP		Fossil fuels must not be used for heating during pyrolysis, except for preheating the pyrolysis reactor.	Mandatory
	Environmental				Pyrolysis gases must not be allowed to escape to the atmosphere- they should be recovered or burned.	Mandatory
	Environmental				Flue gas emissions from the burning of the pyrolysis gas or syngas must be within regulatory emission thresholds.	Mandatory
	Technical				The highest treatment temperature during pyrolysis must not fluctuate by more than 20% in ˚C.	
	Safety			Designer	The design shall include the means to isolate energy sources to permit maintenance.	Mandatory
	Safety	Legislation	Work Health and Safety Act 2011 - C2022C00082	Part 2, Division 3-22.2 – Duties of persons conducting businesses or undertakings that design plant, substances or structures	The designer must ensure, so far as is reasonably practicable, that the plant, substance or structure is designed to be without risks to the health and safety of persons:	Mandatory
	Safety	Legislation	Work	Part 2,	The designer must carry out, or arrange the carrying out of, any	Mandatory

			Health and Safety Act 2011 - C2022C00082	Division 3-22.3 – Duties of persons conducting businesses or undertakings that design plant, substances or structures	calculations, analysis, testing or examination that may be necessary for the performance of the duty imposed by subsection 2	
	Safety	Legislation	Work Health and Safety Act 2011 - C2022C00082	Part 2, Division 3-22.4 – Duties of persons conducting businesses or undertakings that design plant, substances or structures	The designer must give adequate information to each person who is provided with the design for the purpose of giving effect to it concerning: (a) each purpose for which the plant, substance or structure was designed; and (b) the results of any calculations, analysis, testing or examination referred to in subsection (3), including, in relation to a substance, any hazardous properties of the substance identified by testing; and (c) any conditions necessary to ensure that the plant, substance or structure is without risks to health and safety when used for a purpose for which it was designed or when carrying out any activity referred to in subsection 2	Mandatory

		CoP	Code of Practice - Hazardous Manual Tasks	6.1 – Role of designers, manufacturers, importers and suppliers	As a designer of plant or structures used for work, under this regulation you must: • ensure the plant or structure is designed to eliminate the need to carry out a hazardous manual task in connection with the plant or structure • where this is not reasonably practicable, minimise the need to carry out a hazardous manual task in connection with the plant or structure so far as is reasonably practicable, and • give each person who is provided with the design for the purpose of giving effect to it adequate information about the features of the plant or structure that eliminate or minimise the need for any hazardous manual task to be carried out.	Mandatory
		CoP	Code of Practice - Hazardous Manual Tasks	6.1 – Role of designers, manufacturers, importers and suppliers	The design shall provide the following information to third parties for the purpose of manufacture: • the purpose for which the plant or structure was designed • how your design has dealt with hazards that may affect manual tasks, and whether there are any residual risks • how to handle the plant or structure safely, including during its transportation, installation, operation, maintenance and disposal.	Mandatory
		CoP	Code of Practice – Managing Noise And Preventing Hearing Loss At Work	6.1 – Role of designers, manufacturers, importers, suppliers and	Designers must provide information on the noise emission values of the plant, the operating conditions of the plant when the noise emission is measured, and the methods used to measure the noise emission.	Mandatory

				installers of plant, substances or structures		
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	59.1 Duties of designers, manufacturers, importers and suppliers of plant	A designer of plant must ensure that the plant is designed so that its noise emission is as low as is reasonably practicable.	Mandatory
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	59.2 Duties of designers, manufacturers, importers and suppliers of plant	A designer of plant must give to each person who is provided with the design for the purpose of giving effect to it adequate information about: (a) the noise emission values of the plant; and (b) the operating conditions of the plant when noise emission is to be measured; and (c) the methods the designer has used to measure the noise emission of the plant.	Mandatory
		Regulations	Safe Work Australia- Model Work Health and	61.1 Duties of designers, manufacturers,	A designer of plant or a structure must ensure that the plant or structure is designed so as to eliminate the need for any hazardous manual task to be carried out in connection with the plant or structure.	Mandatory

			Safety Regulations	importers and suppliers of plant or structures		
		Regulations	Safe Work Australia-Model Work Health and Safety Regulations	61.2 Duties of designers, manufacturers, importers and suppliers of plant or structures	If it is not reasonably practicable to comply with subregulation (1), the designer must ensure that the plant or structure is designed so that the need for any hazardous manual task to be carried out in connection with the plant or structure is minimised so far as is reasonably practicable	Desireable
		Regulations	Safe Work Australia-Model Work Health and Safety Regulations	61.3 Duties of designers, manufacturers, importers and suppliers of plant or structures	The designer must give to each person who is provided with the design for the purpose of giving effect to it adequate information about the features of the plant or structure that eliminate or minimise the need for any hazardous manual task to be carried out in connection with the plant or structure.	Mandatory
		Regulations	Safe Work Australia-Model	187 Provision of information	A designer of plant must ensure, when the design of the plant is made available to the manufacturer of the plant, that the manufacturer is provided with:	Mandatory

			Work Health and Safety Regulations	to manufacturer	(a) information to enable the plant to be manufactured in accordance with the design specifications; and (b) if applicable, information about: (i) the installation, commissioning, decommissioning, use, handling, storage and, if the plant is capable of being dismantled, dismantling of the plant; and (ii) the hazards and risks associated with the use of the plant that the designer has identified; and (iii) testing or inspections to be carried out on the plant; and (iv) the systems of work and competency of operators that are necessary for the safe use of the plant; and (v) the emergency procedures (if any) that are required to be implemented if there is a malfunction of the plant.	
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	189.2 Guarding	The designer must ensure, so far as is reasonably practicable, that the guarding designed for that purpose will prevent access to the danger point or danger area of the plant.	Mandatory
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	189.3 Guarding	(3) The designer must ensure that: (a) if access to the area of the plant requiring guarding is not necessary during operation, maintenance or cleaning of the plant—the guarding is a permanently fixed physical barrier; or (b) if access to the area of the plant requiring guarding is necessary during operation, maintenance or cleaning of the plant—the guarding is an interlocked physical barrier that allows access to the area being guarded at times when that area does not present a risk and prevents access to that area at any	Mandatory

					other time; or (c) if it is not reasonably practicable to use guarding referred to in paragraph (a) or (b)—the guarding used is a physical barrier that can only be altered or removed by the use of tools; or (d) if it is not reasonably practicable to use guarding referred to in paragraph (a), (b) or (c)—the design includes a presencesensing safeguarding system that eliminates any risk arising from the area of the plant requiring guarding while a person or any part of a person is in the area being guarded.	
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	189.4 Guarding	The designer must ensure that the guarding is designed: (a) to be of solid construction and securely mounted so as to resist impact or shock; and (b) to make bypassing or disabling of the guarding, whether deliberately or by accident, as difficult as is reasonably practicable; and (c) so as not to cause a risk in itself.	Mandatory
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	189.5 Guarding	If the plant to be guarded contains moving parts and those parts may break or cause workpieces to be ejected from the plant, the designer must ensure, so far as is reasonably practicable, that the guarding will control any risk from those broken or ejected parts and workpieces.	Mandatory
		Regulations	Safe Work Australia- Model Work Health and	189.6 Guarding	Despite anything to the contrary in this regulation, the designer must ensure: (a) that the guarding is of a kind that can be removed to allow maintenance and cleaning of the plant at any time that the plant is not in normal operation; and	Mandatory

			Safety Regulations		(b) if the guarding is removed, that, so far as is reasonably Practicable	
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	190.1 Operational controls	A designer of plant must ensure that the design provides for any operator's controls for the plant to be: (a) identified on the plant so as to indicate their nature and function and direction of operation; and (b) located so as to be readily and conveniently operated by each person using the plant; and (c) located or guarded to prevent unintentional activation; and (d) able to be locked into the "off" position to enable the disconnection of all motive power.	Mandatory
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	190.2 Operational controls	If the need for plant to be operated during maintenance or cleaning cannot be eliminated, the designer of the plant must ensure that the design provides for operator's controls that: (a) permit operation of the plant while a person is undertaking the maintenance or cleaning of the plant; and (b) while the plant is being maintained or cleaned, cannot be operated by any person other than the person who is carrying out the maintenance or cleaning of the plant; and (c) will allow operation of the plant in such a way that any risk associated with the activities in relation to any person who is carrying out the maintenance or cleaning: (i) is eliminated so far as is reasonably practicable; or (ii) if it is not reasonably practicable to eliminate the risk, is minimised so far as is reasonably practicable.	Mandatory
		Regulations	Safe Work Australia- Model	191.1 Emergency stop	(1) If plant is designed to be operated or attended by more than 1 person and more than 1 emergency stop control is fitted, the designer of the plant must ensure that the design provides for the	Mandatory

			Work Health and Safety Regulations	controls	multiple emergency stop controls to be of the "stop and lock-off" type so that the plant cannot be restarted after an emergency stop control has been used unless that emergency stop control is reset.	
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	191.2 Emergency stop controls	If the design of the plant includes an emergency stop control for the plant, the designer of the plant must ensure that the design provides: (a) for the stop control to be prominent, clearly and durably marked and immediately accessible to each operator of the plant; and (b) for any handle, bar or push button associated with the stop control to be coloured red; and (c) that the stop control cannot be adversely affected by electrical or electronic circuit malfunction.	Mandatory
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	192.1 Warning devices	This regulation applies if the design of plant includes an emergency warning device or it is necessary to include an emergency warning device to minimise risk.	Mandatory
		Regulations	Safe Work Australia- Model Work Health and Safety Regulations	192.2 Warning devices	The designer of the plant must ensure that the design provides for the device to be positioned on the plant to ensure the device will work to best effect.	Mandatory

		Regulations	Safe Work Australia-Model Work Health and Safety Regulations	229.1 Record of standards or engineering principles used	If the design of plant is required to be registered under Part 5.3, the designer of the plant must record any published technical standard, including any part of a published technical standard, that was used to design the plant.	Mandatory
		Regulations	Safe Work Australia-Model Work Health and Safety Regulations	229.2 Record of standards or engineering principles used	If the designer of the plant has not used published technical standards to design the plant, the designer must record any engineering principles used to design the plant.	Mandatory

Appendix F Material Properties

Properties	**Carbon Steels**	**Alloy Steels**	**Stainless Steels**
Density (kg/m3)	7.85 x 10^3	7.85 x 10^3	7.75-8.1 x 10^3
Elastic Modulus (GPa)	190-210	190-210	190-210
Poisson's Ratio	0.27-0.3	0.27-0.3	0.27-0.3
Thermal Expansion	11-16.6 x 10^{-6}	9-15 x 10^{-6}	9-20.7 x 10^{-6}
Melting Point (°C)	1425-1540	14415	1510
Thermal Conductivity (W/m-K)	24.3-65.2	26-48.6	11.2-36.7
Specific Heat (J/kg-K	450-2081	452-1499	420-500
Tensile Strength (MPa)	276-1882	758-1882	515-828
Yield Strength (MPa)	186-758	366-1793	207-552
Cost $/kg	0.5		2

MOST POPULAR CARBON STEEL GRADES AND THEIR APPLICATIONS		
LOW CARBON STEEL (MILD STEEL)		
Popular steel grades	**Characteristics**	**Applications**
A36	It is strong, tough ductile, formable, and weldable, easily machined, welded and formed, making it extremely useful as a general-purpose steel	Components in the automotive, construction, heavy equipment, and oil and gas industries

MEDIUM CARBON STEELS		
Popular steel grades	**Characteristics**	**Applications**
1045	Has good weldability, good machinability, and high strength and impact properties	Gears, pins, rams, shafts, rolls, sockets, axles, spindles, worms

ALLOY STEELS		
Popular steel grades	**Characteristics**	**Applications**
	Compared to carbon steel, higher strength, hardness toughness, wear resistance and corrosion resistance	Construction and architecture where strength, toughness and corrosion resistance are a pre-requisite.

AUSTENITIC STAINLESS STEEL GRADES		
Popular steel grades	**Characteristics**	**Applications**
304	304 stainless steel is the most common type used in the kitchen. It has a bright shine due to a high level of chromium and nickel. Its aso very resistant to corrosion and rust, although its susceptible to corrosion caused by exposure to salt	Kitchen appliances, internal parts, kitchen utensils, small wares, flatware, prep tables.
316	316 stainless steel is the second most common type used and its alloy includes an additional element, molybdenum, which increases its resistance to corrosion caused by salt and other chemicals.	Kitchen equipment, grills high end cookware, equipment and furniture used outdoors and in salty environments.

FERRITIC STAINLESS STEEL GRADES		
Popular steel grades	**Characteristics**	**Applications**
430	430 stainless steel contains a very small amount of nickel, and it’s not a corrosion resistant as the 300 series.	Medium quality flatware prep tables appliances induction ready cookware.

DUPLEX STAINLESS STEEL GRADES		
Popular steel grades	**Characteristics**	**Applications**
2205	Duplex 2205 is the most widely used duplex steel with excellent corrosion resistance. The microstructure provides resistance to stress corrosion cracking and ensures high strength	Heat exchangers, pressure vessels, tanks, tubes and pipes for different industries including oil and gas.

Appendix G Design Drawings

List of Drawings:

SSPM-GA-001 General Arrangement

SSPM-C-001 Lid

SSPM-A-002 Air Manifold

SSPM-C-003 Outer Drum

SSPM-C-004 Inner Drum

SSPM-C-007a Support Frame Base

SSPM-C-007b Support Frame Platform

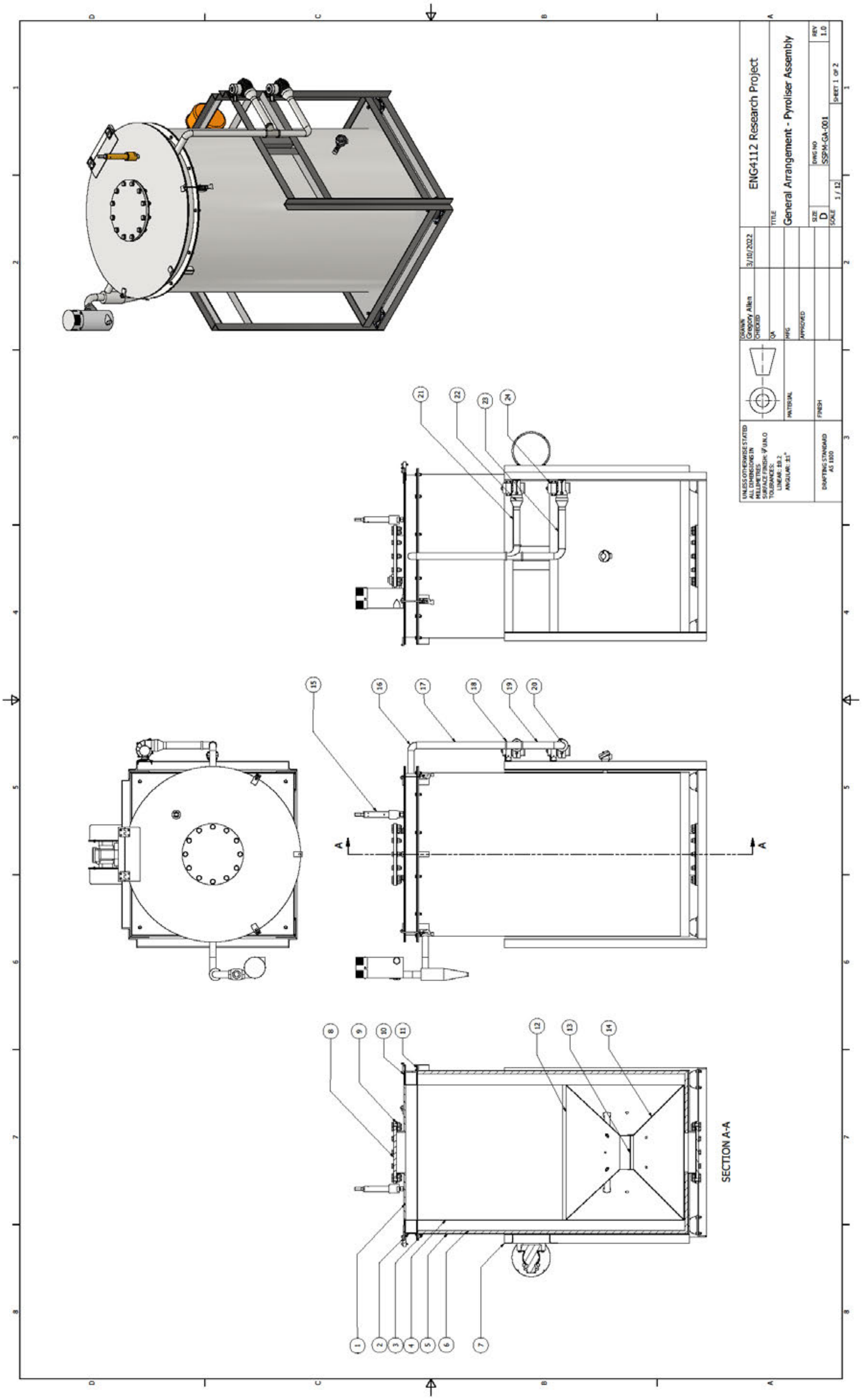
SSPM-A-014 Nozzle Assembly

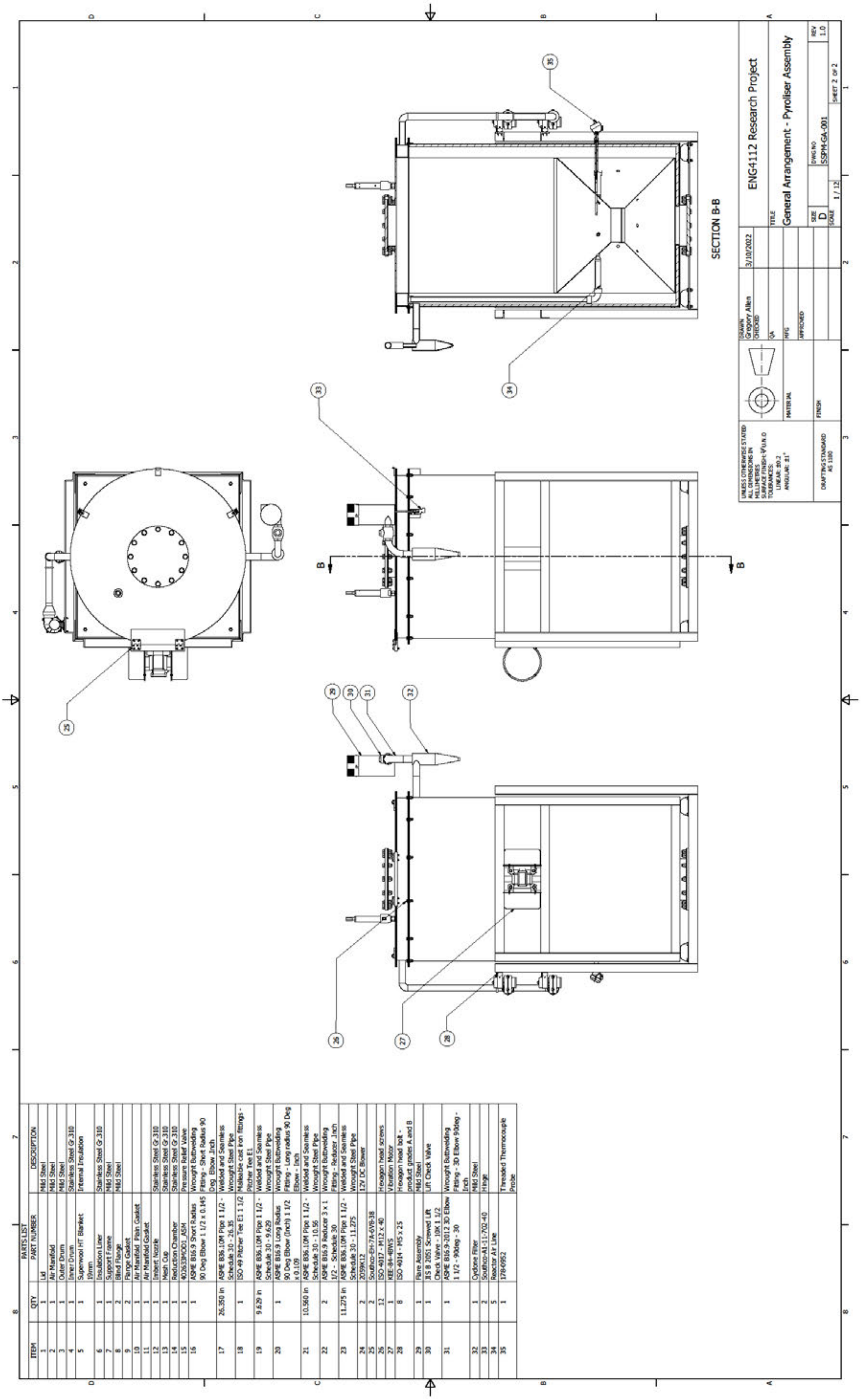
SSPM-A-029 Flare Assembly

SSPM-C-032 Cyclone Filter

Gregory Allen [redacted]

ENG4111 - Research Project Part 1: Design Drawings





PARTS LIST

ITEM	QTY	PART NUMBER	DESCRIPTION
1	1	Lid	Mild Steel
2	1	Air Manifold	Mild Steel
3	1	Outer Drum	Mild Steel
4	1	Inner Drum	Stainless Steel Gr.310
5	1	Superwool HT Blanket 19mm	Internal Insulation
6	1	Insulation Liner	Stainless Steel Gr.310
7	1	Support Frame	Mild Steel
8	2	Blind Flange	Mild Steel
9	2	Flange Gasket	
10	1	Air Manifold Plain Gasket	
11	1	Air Manifold Gasket	
12	1	Imbert Nozzle	Stainless Steel Gr.310
13	1	Mesh Cup	Stainless Steel Gr.310
14	1	Reduction Chamber	Stainless Steel Gr.310
15	1	402633MOD1_ASM	Pressure Relief Valve
16	1	ASME B16.9 Short Radius 90 Deg Elbow 1 1/2 x 0.145	Wrought Buttwelding Fitting - Short Radius 90 Deg Elbow .Inch
17	26.350 in	ASME B36.10M Pipe 1 1/2 - Schedule 30 - 26.35	Welded and Seamless Wrought Steel Pipe
18	1	ISO 49 Pitcher Tee E1 1 1/2	Malleable cast iron fittings - Pitcher Tee E1
19	9.629 in	ASME B36.10M Pipe 1 1/2 - Schedule 30 - 9.629	Welded and Seamless Wrought Steel Pipe
20	1	ASME B16.9 Long Radius 90 Deg Elbow (Inch) 1 1/2 x 0.109	Wrought Buttwelding Fitting - Long radius 90 Deg Elbow - Inch
21	10.560 in	ASME B36.10M Pipe 1 1/2 - Schedule 30 - 10.56	Welded and Seamless Wrought Steel Pipe
22	2	ASME B16.9 Reducer 3 x 1 1/2 - Schedule 30	Wrought Buttwelding Fitting - Reducer .Inch
23	11.275 in	ASME B36.10M Pipe 1 1/2 - Schedule 30 - 11.275	Welded and Seamless Wrought Steel Pipe
24	2	2059K12	12V DC Blower
25	2	Southco-EH-7A-6V8-38	
26	12	ISO 4017 - M12 x 40	Hexagon head screws
27	1	KEE-84-48WS	Vibration Motor
28	8	ISO 4014 - M5 x 25	Hexagon head bolt - product grades A and B
29	1	Flare Assembly	Mild Steel
30	1	JIS B 2051 Screwed Lift Check Valve - 10K 1 1/2	Lift Check Valve
31	1	ASME B16.9-2012 3D Elbow 1 1/2 - 90deg - 30	Wrought Buttwelding Fitting - 3D Elbow 90deg - Inch
32	1	Cyclone Filter	Mild Steel
33	2	Southco-A1-11-702-40	Hinge
34	5	Reactor Air Line	
35	1	178-0952	Threaded Thermocouple Probe

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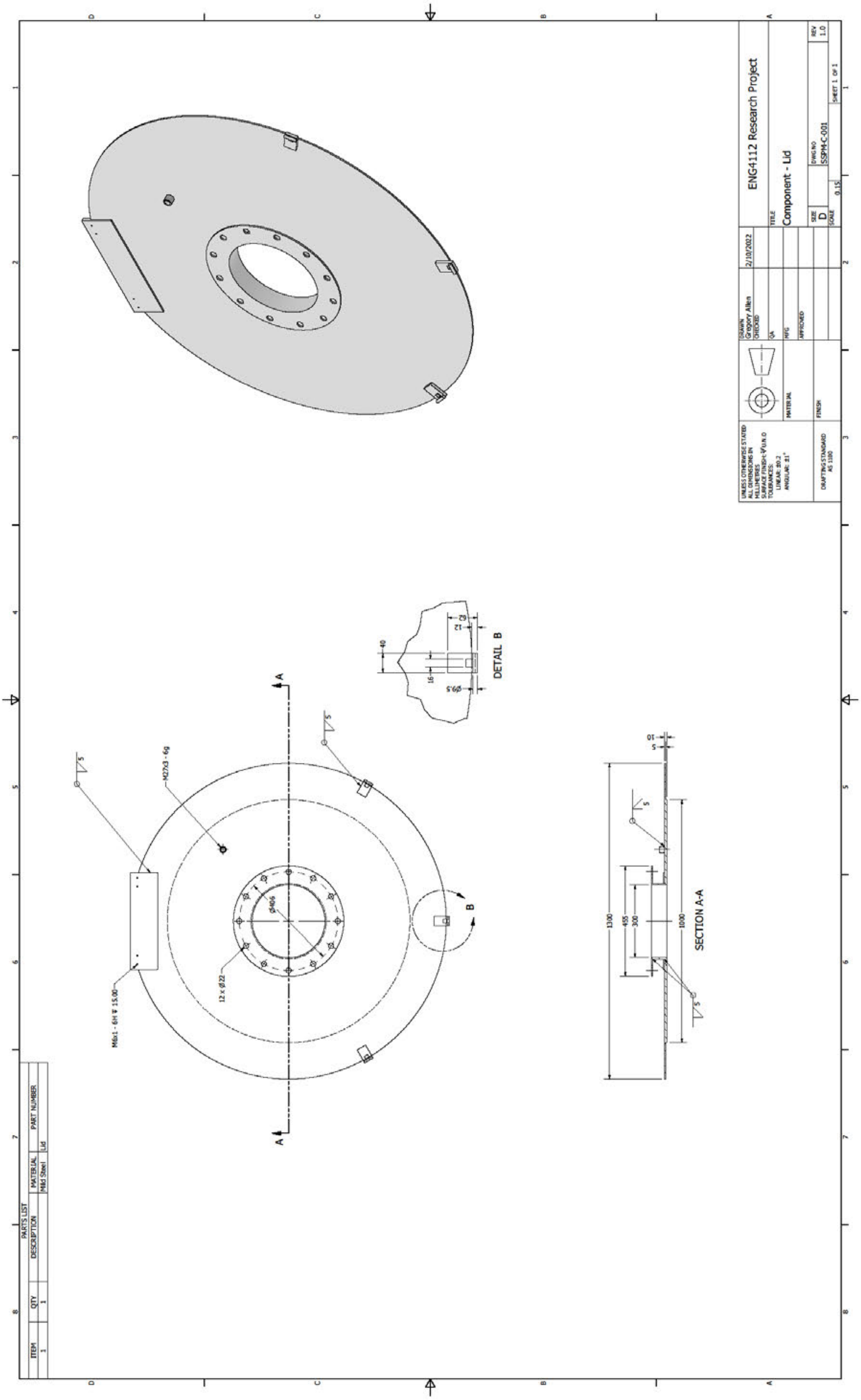
ENG4111 - Research Project Part 1: Design Drawings



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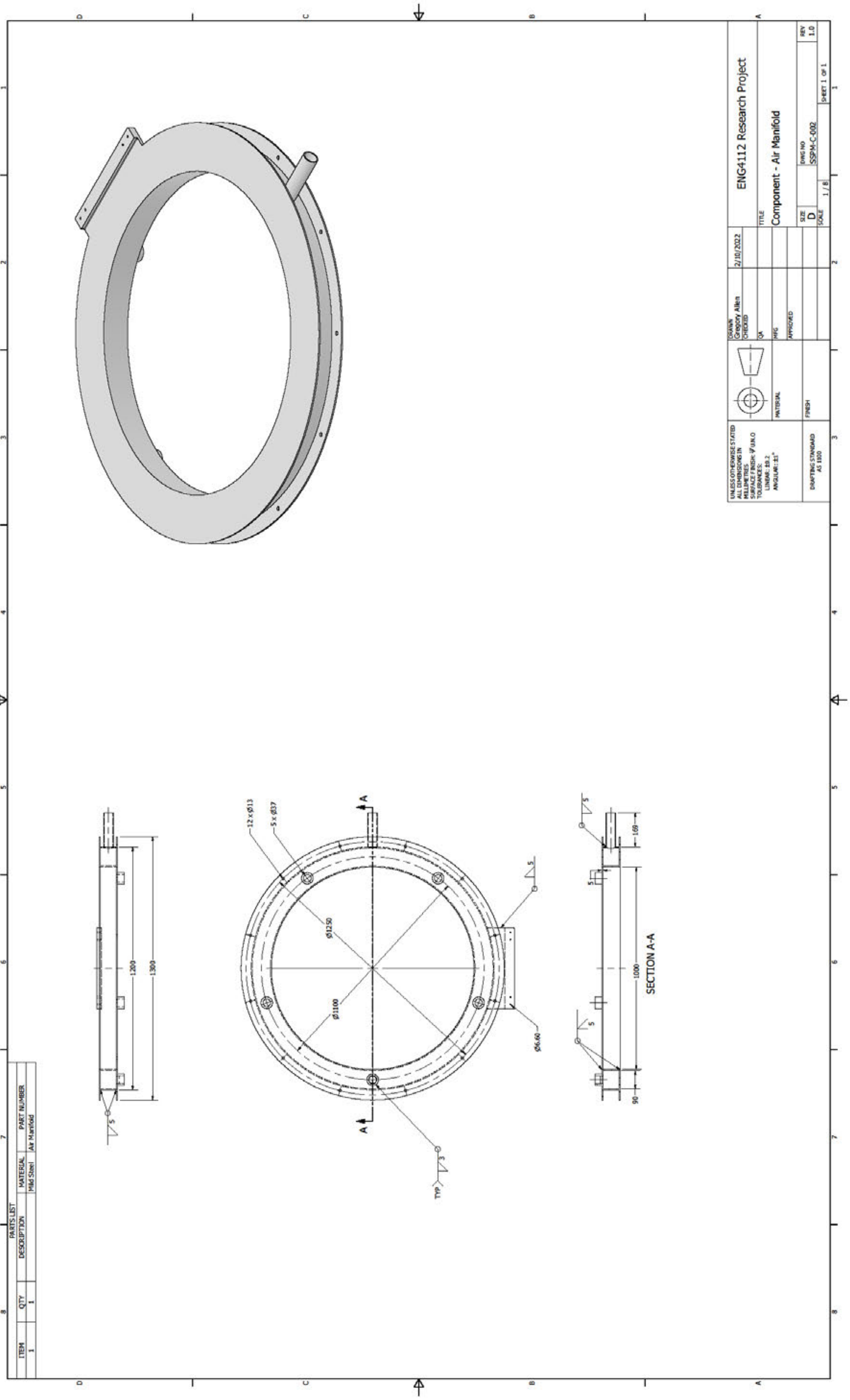
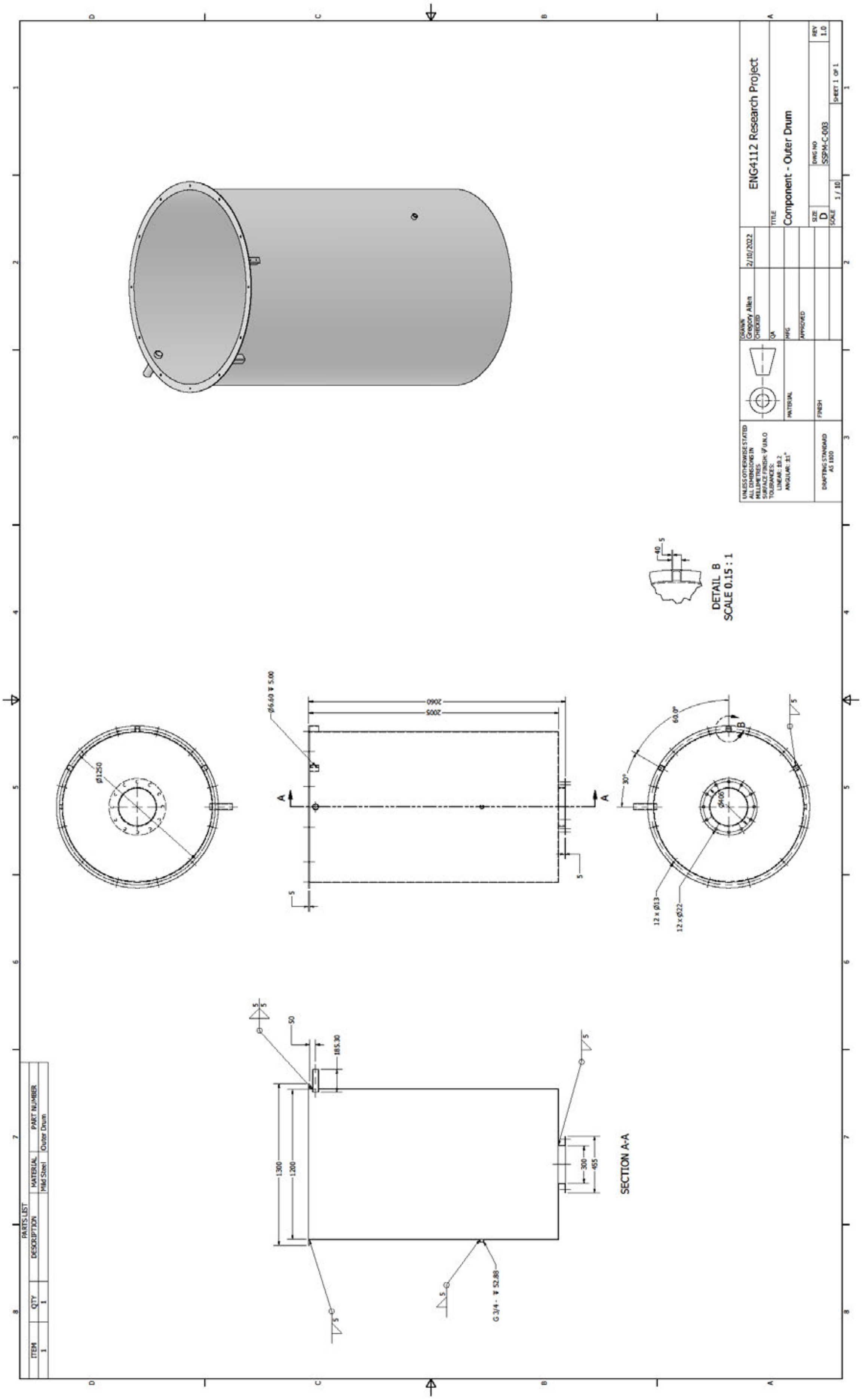
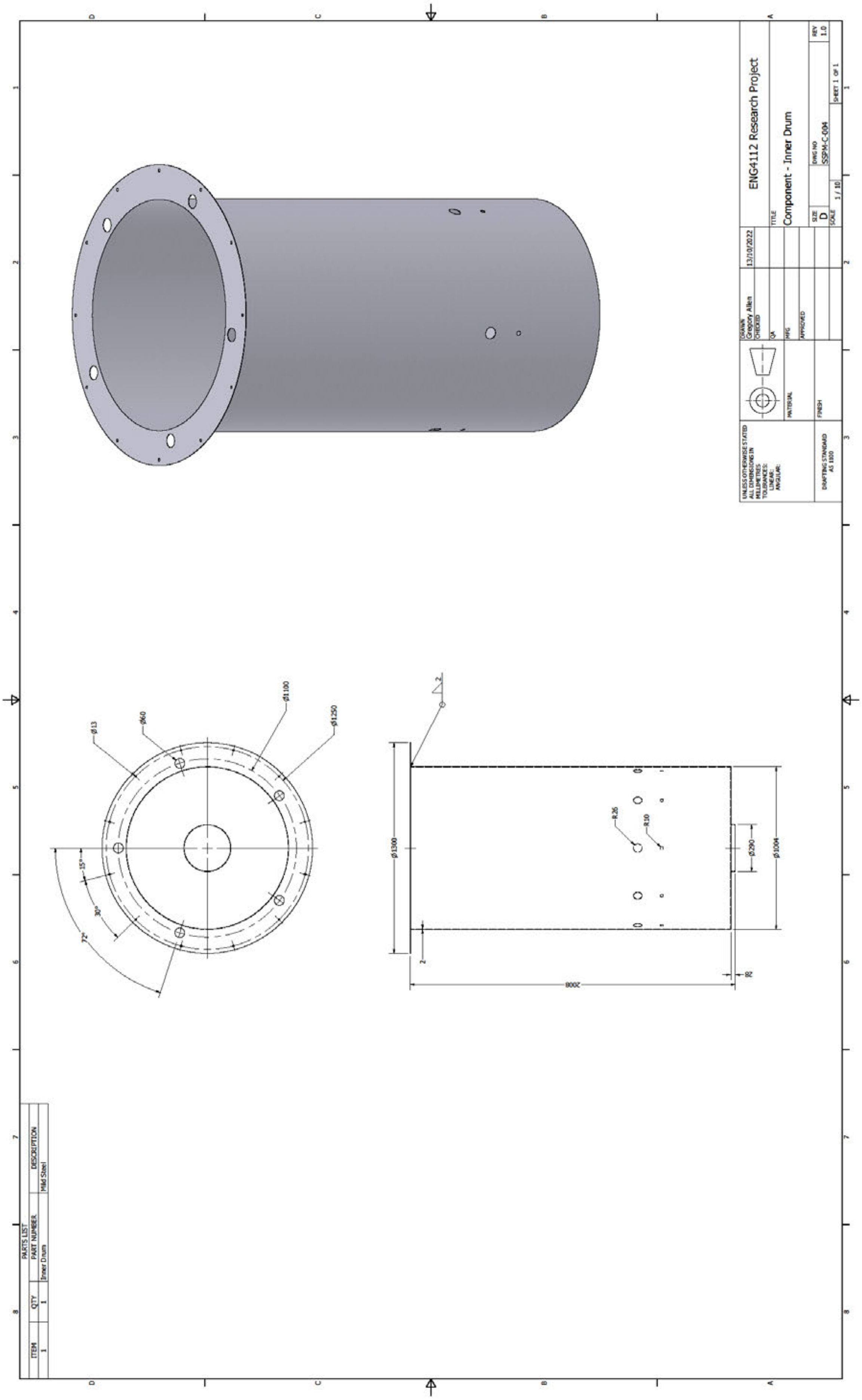
ENG4111 - Research Project Part 1: Design Drawings




ENG4112 Research Project
Component - Outer Drum
SSPM-C-003
Gregory Allen
2/10/2022
DETAIL B
SCALE 0.15 : 1
SECTION A-A
PARTS LIST
Mild Steel
Outer Drum

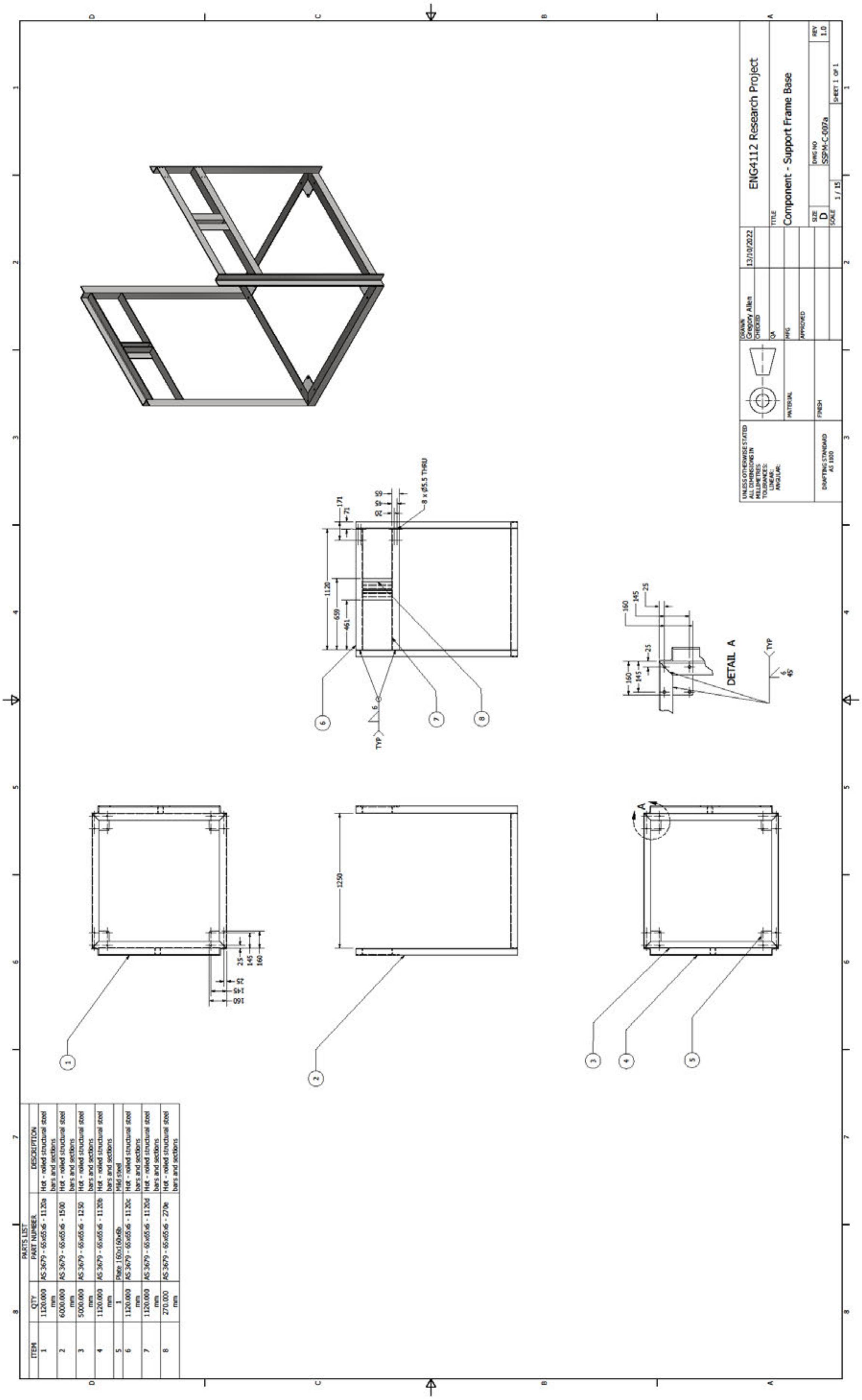
Gregory Allen [redacted]

ENG4111 - Research Project Part 1: Design Drawings



Gregory Allen [redacted]

ENG4111 - Research Project Part 1: Design Drawings



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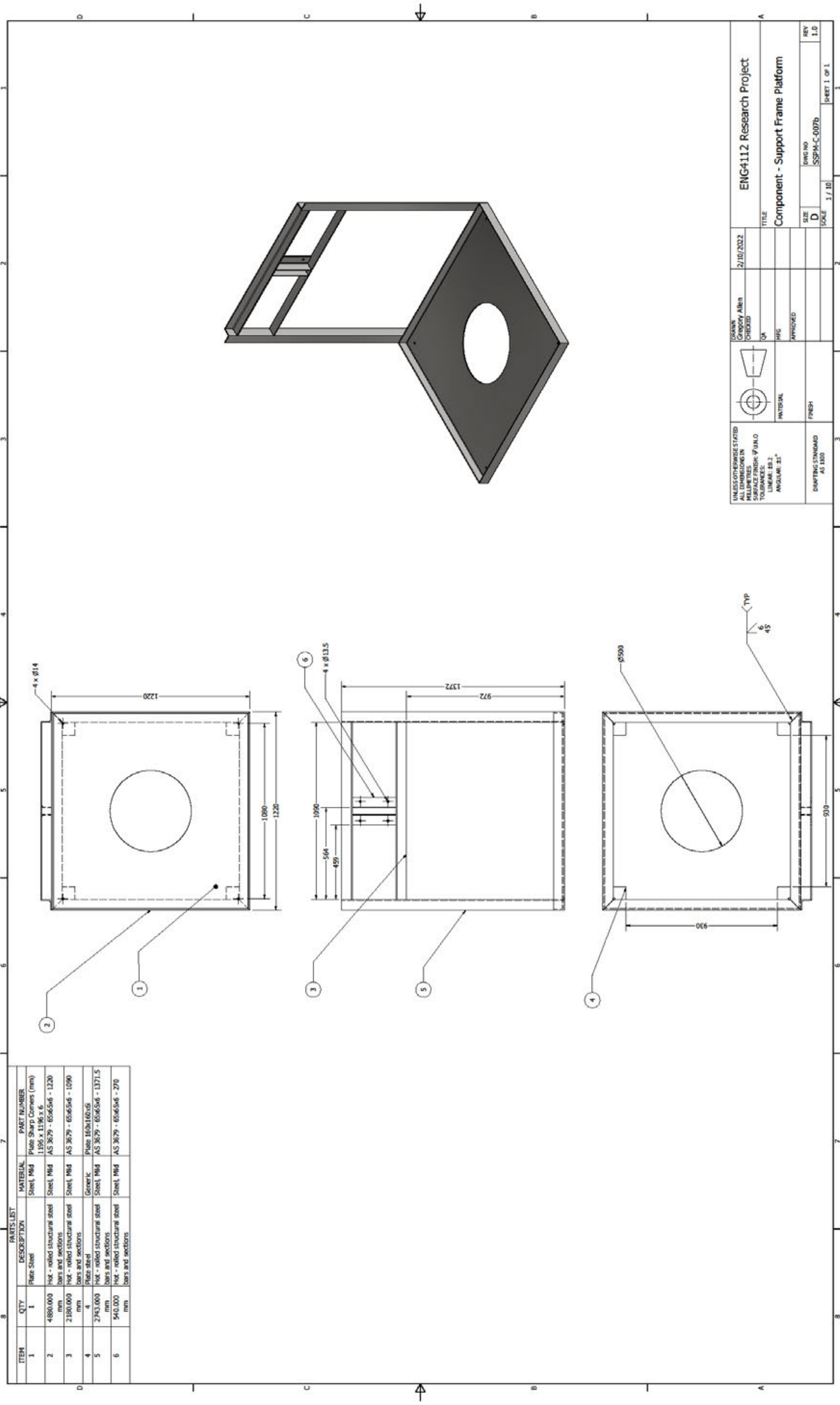

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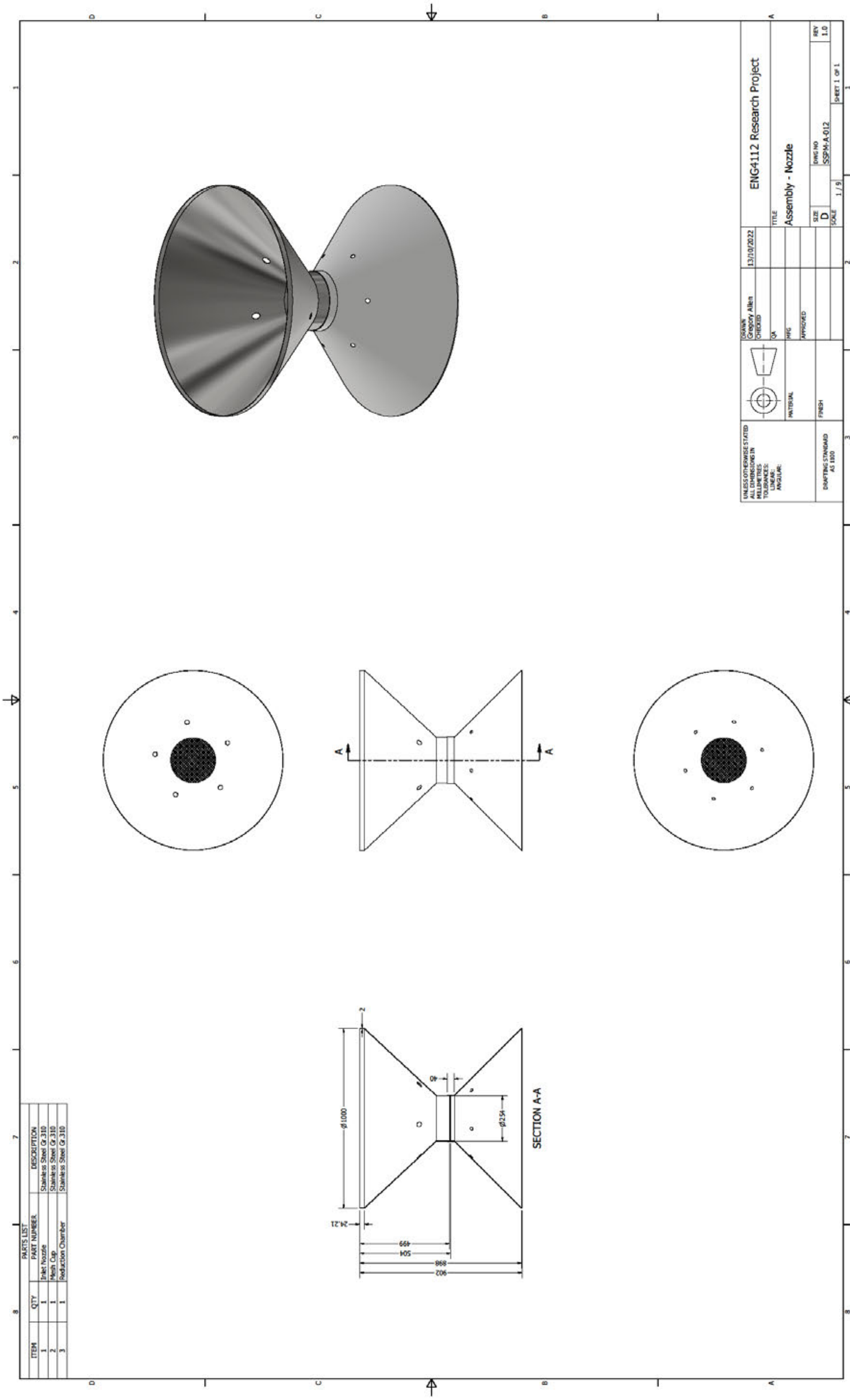

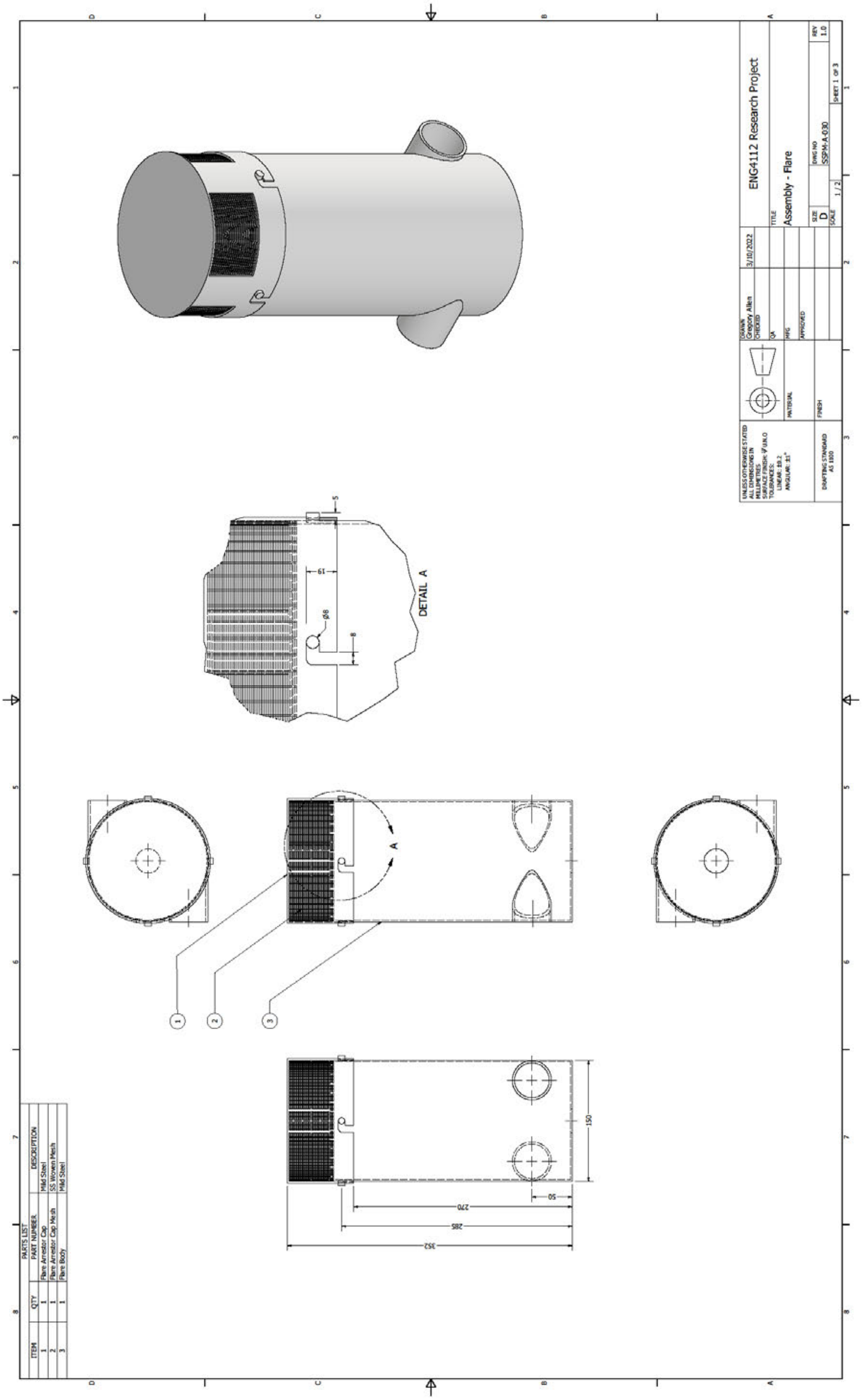
ENG4112 Research Project
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REV 1.0
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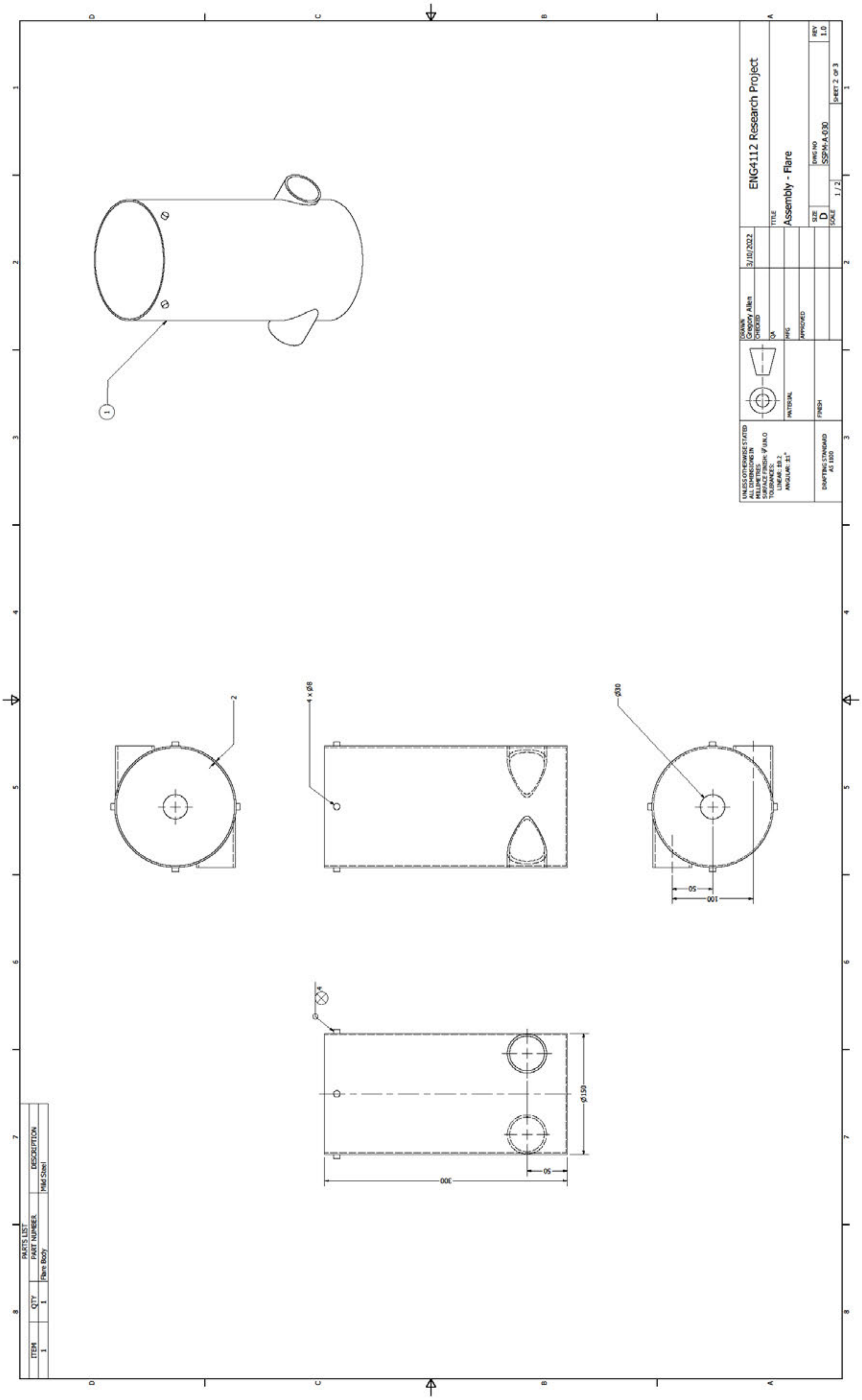
SHEET 1 OF 3
DRAWN Gregory Allen 3/10/2022
CHECKED
QA
MFG
APPROVED
MATERIAL
FINISH
DRAFTING STANDARD AS 1100
DETAIL A
PARTS LIST
ITEM QTY PART NUMBER DESCRIPTION
1 1 Flare Arrestor Cap Mild Steel
2 1 Flare Arrestor Cap Mesh SS Woven Mesh
3 1 Flare Body Mild Steel
352
285
270
150
50

Gregory Allen [redacted]

ENG4111 - Research Project Part 1: Design Drawings



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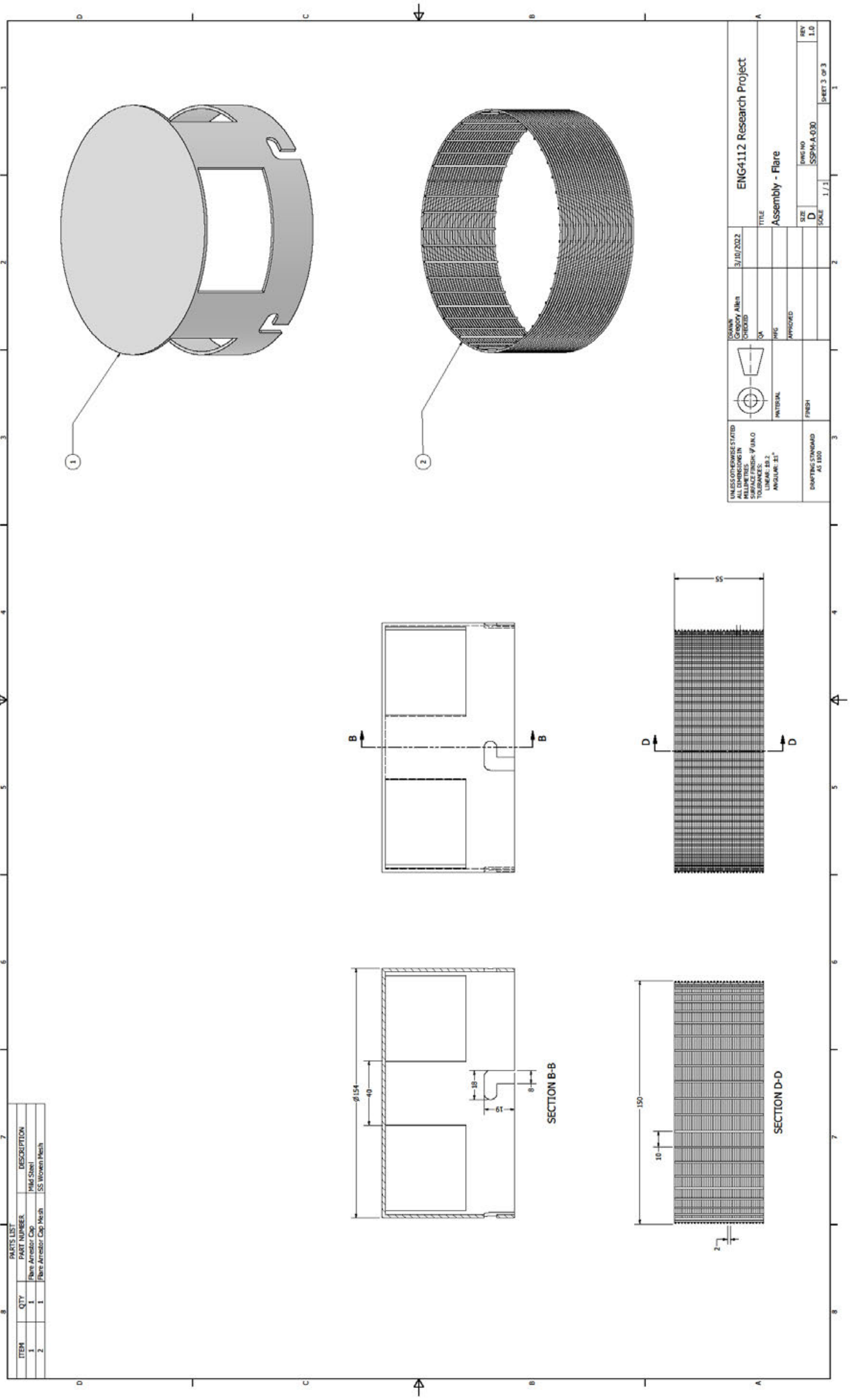

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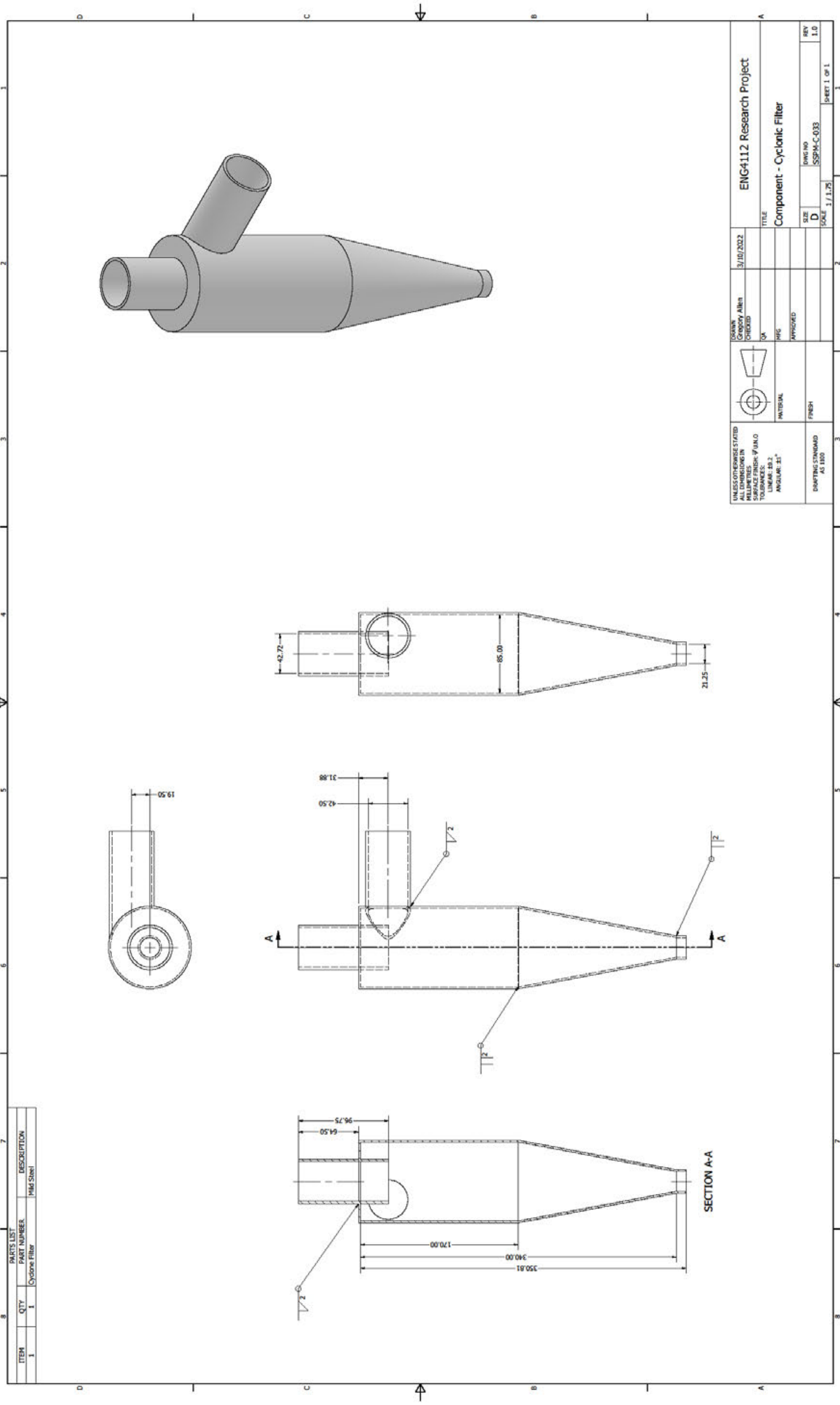

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